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REFRACTORIES
AND FURNACES

PROPERTIES, PREPARATION, AND APPLICATION OF MATERIALS USED IN THE CONSTRUCTION AND OPERATION OF FURNACES

BY

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The U. S. Metals Refining Co.*

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To

J. B. WYNNE

PREFACE

Some notes on furnace linings, breasts and packings, made during the author's activities as superintendent of furnaces, formed the original basis in the preparation of this book. But since no serious effort has ever been made to collect the scattered information on the properties and preparation of the materials of which industrial furnaces are constructed, considerable space has been devoted to descriptions of the sources, and processes of manufacture, of refractories with the object of presenting, to those interested in refractory materials and in the operation of furnaces, a comprehensive study of the physical and chemical properties of these materials.

The author has attempted also to coördinate the study of methods of preparing and testing refractory materials and of constructing furnaces, and has tried to systematise the data on the many kinds of cements, and packing and fettling mixtures which have their usefulness under special conditions in promoting efficiency in furnace campaigns and in reducing the ever-high cost item of furnace repairs and masonry.

Since personal acquaintanceship with all kinds of industrial furnaces is not possible, the author has been obliged to supplement his field notes by use of the data prepared by men who have worked in other fields. While due acknowledgements of the sources of such information have been given, some special mention should be made of the work of Kerl, Bischof, Richardson, Ries, Fitzgerald and Hering, to whose publications the student is referred for special information on subjects allied to the main theme of this book.

The author wishes to express gratitude to the Bureau of Mines, to the various engineering experiment stations and to the technical press of Germany, England, France and America, for the considerable attention they have given, in their publications, to features marking progress in the development of truly refractory furnace materials.

Much valuable aid has been given by The Harbison-Walker Refractories Co., The Laclede Christy Co., The Norton Company, The

American Refractories Co., The Chicago Firebrick and Retort Co.; The Mexico Firebrick Co., Messrs. Evens and Howard, Messrs. Didier-March, The Allis-Chalmers Company, The Clearfield Machine Shops, The American Clay Machinery Co., and Messrs. Raymond. The author is also indebted to Metallurgical and Chemical Engineering, Engineering and Mining Journal, Mining and Scientific Press, American Gas-Light Journal, Clayworker, Brick, and Die Thonindustrie Zeitung; and to Professors Orton of Ohio State University, Ries of Cornell University, Bleininger of the University of Illinois, Watts of the University of Wisconsin, Dr. Weidman and Mr. McNight. The author is especially grateful to Mr. Kenneth Seaver, whose generous counsel has been of as much assistance in the preparation of the book as the material data which he very kindly supplied.

The book as presented does not represent so much an attempt to write the last word on Refractories and Furnaces as an endeavour, in covering the subject, to create some kind of order out of the chaos which has enveloped the study of an important metallurgical science, *that of the construction of good furnaces from properly prepared materials.*

F. T. HAVARD.

CHICAGO, *November*, 1912.

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REFRACTORIES AND FURNACES

INTRODUCTION

NOTES ON THE HISTORY AND DEVELOPMENT OF THE FIRE-CLAY AND REFRACTORIES INDUSTRY

It would tax the imagination of the most enthusiastic antiquarian to set a date for the beginning of the clay-working era. Since even the birds and beasts use clay and earth in their nests and lairs, we may have no doubt that neolithic man was a potter of no small skill. He must very soon have realized that some of the earthy materials, which he found beside the streams, lent themselves to being shaped into vessels which, though porous, would hold water. He would quickly have found that these vessels became firmer when dried in the sun; again that they rapidly lost this firmness and became soft when filled with water. Later he learnt that the clays could be made permanently firm and water-tight by heating. Such burnt-clay pottery was indeed made by prehistoric man. Also the discovery of glazing must have taken place at about the same time, for often the contact of pot and hot ashes would result in producing a glazed surface on the clay.

Archæological investigations prove that bricks were used in Egypt as far back as 1200 years B.C. The height of a stadium about the temple of Belus, built at this time, was some 700 feet, and a brick wall, eight miles in circumference, surrounded the whole. Some pyramids were built of brick, and one, built by King Asychis, bore a stone plate with an inscription to the effect that the brick pyramid regarded itself as towering above the stone pyramids as Zeus over the gods.

The earliest stone arches carried a brick keystone made from the clay of the Nile. From the Old Testament we learn that the Tower of Babel was built of bricks and that the principal occupation of the children of Israel, while in captivity in Egypt, was brickmaking. Particular attention was paid to the burning of the bricks, and we are told that those in the Tower of Babel were especially well burned. Some of the walls of Babylon were made of bricks glazed in the most beautiful colors. Even porcelain remains have been discovered in Egyptian tombs which antedate the Roman period. Such ware, however, was probably introduced from the Orient.

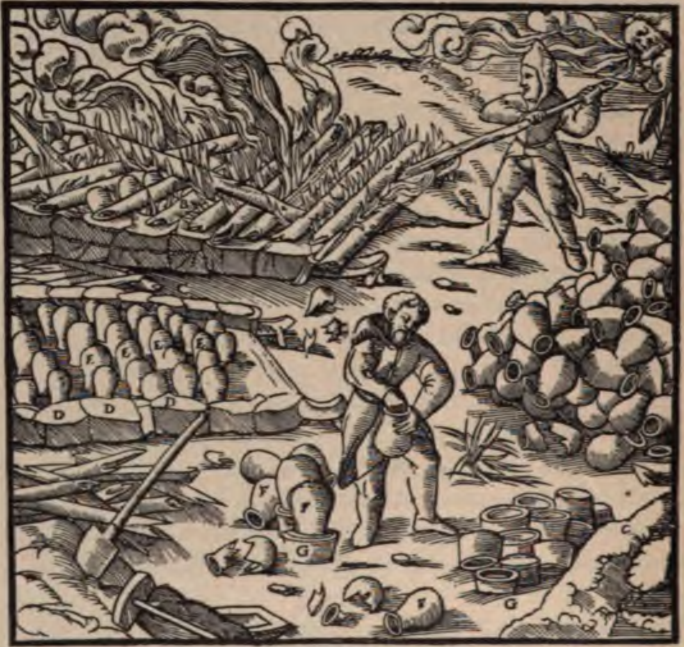

Fig. 1.—The Preparation of Crucibles in the Fifteenth Century. (From Agricola:—"De Re Metallica.")

The Greeks and Romans made pottery and earthenware, and used bricks of many kinds. These latter are described by Vetruvius under the names of "Lateres" and "Testæ"; the "lateres crudi" correspond to our adobes or sun-dried mud bricks and the "testae" or "lateres cocti" to burned bricks.

From Rome the mason's art spread over the whole of Europe. Yet brick buildings did not become general until the fourteenth century, and it was only in the seventeenth century that the art of the mason and the skill of the brickmaker combined to produce results at all comparable with those of our own day.

With the development of the ceramic and metallurgical industries, demands were made for bricks and furnace materials which would stand higher temperatures than had hitherto been used. With the advent of the chemist and the geologist, progress was made in the selecting and the application of those clays which would meet the new requirements in both a physical and chemical sense.

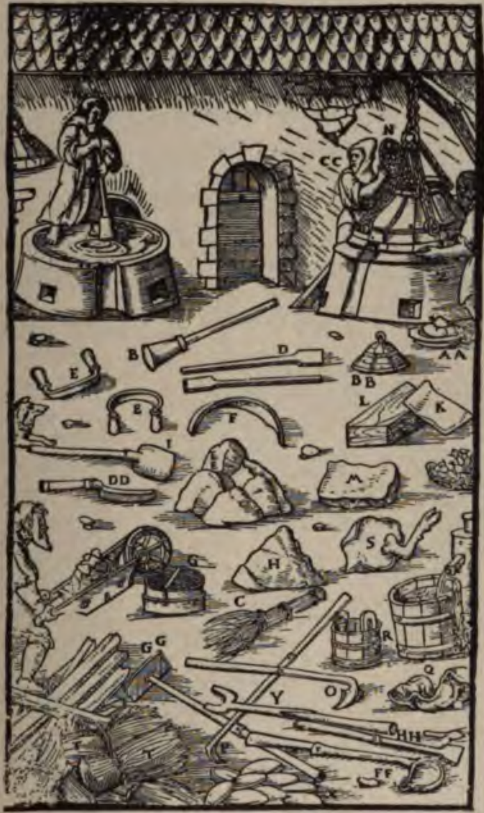

Fig. 2. — The Mediæval Cupelling Hearth. (Agricola.)

The mediæval alchemist was possessed of considerable information concerning the various clays and cleverly applied it in making fire-resisting retorts, crucibles and furnaces. Agricola describes the methods used in making retorts and crucibles of fire clay, and the practice in constructing furnaces. The clay was pugged, moulded, dried and burned in wood fires. The hearth furnaces were similar to the cupelling furnaces used at the present time in Germany, of which the movable roof, made of tile nicely fitted to form an arch inside a round angle-iron band, is a special feature.

The ceramic art of Egypt and the Orient found expression in beautiful forms and glazes among the Greeks and the Romans.

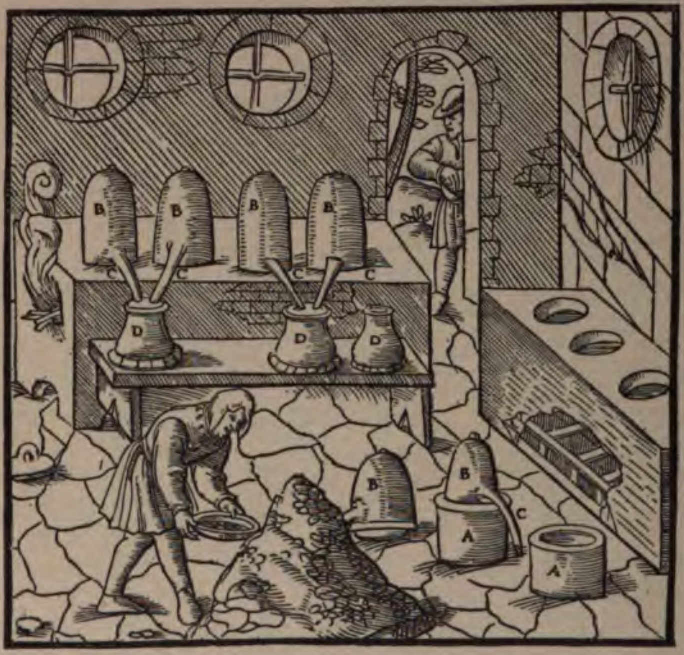

Fig. 3. — Mediæval Retorts. (Agricola.)

In the early part of the Christian Era the art of making such pottery was lost. The Moors revived the industry in Europe and produced the glazed ware the name of which is majolica, derived from the island of Majorca.

The manufacture of fine hard porcelain from clay which burned to a semi-translucent body dates back at least to the ninth century, and spread from the Orient to Europe, where in the seventeenth century it reached some degree of refinement. In 1710 the Meissen porcelain works were founded and took the lead, which they still hold, in producing hard white porcelain.

The manufacture of china-clay wares was introduced into England by Astbury, in 1725. A few years later Wedgewood made fire-resisting white ware, colored household china and highly æsthetic and skilfully wrought statuary and decorative pottery. In fact almost all the beautiful household china of to-day is fashioned and decorated after samples of Wedgewood, and the works which he founded at Etruria still reproduce his masterpieces.

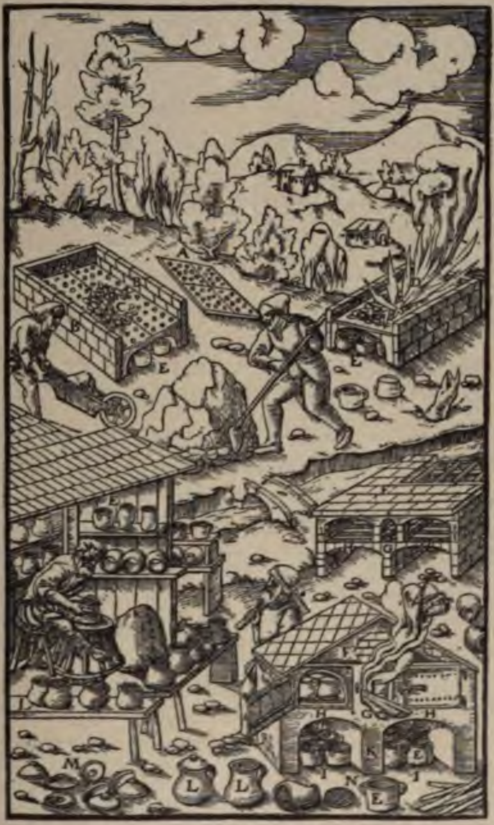

FIG. 4. — The Potter and Metallurgist in the Fifteenth Century. (Agricola.)

The growth of the fire-brick industry was gradual. Refractory clay bricks were produced, as the industries called for them, during the eighteenth and nineteenth centuries. The infusible constituent of porcelain and, indeed, of all clayware is kaolin. Its essential constituent is the mineral kaolinite, the other ingredients being silica and dirt. The name is derived from a mountain of feldspar in China; which, in disintegrating, supplied much kaolinite suitable for the manufacture of porcelain. The first-class refractory bricks and vessels, which are made from clays, contain considerable kaolin and but little quartz; the silica refractories have much silica and little kaolin. It is hard to fuse either alone; mixed they fuse with comparative ease.

In Europe the potter's art preceded that of the brickmaker; in the United States the brick industry was first established in 1640 when some Dutch settlers on Long Island erected brickyards and, later, potteries. While the manufacture of brick has been continuously growing, the potteries have had a checkered development. But now the manufacture of clay products ranks as one of the important industries; its value follows closely that of iron and coal.

The character of the clay brick, which up to a comparatively recent date, was used for general purposes, was not suitable for withstanding the very high temperatures produced in the furnaces, which it was necessary to build to meet the improved methods of smelting ores and metals. Indeed, it was found that some of the more highly silicious natural rocks, such as pudding stone, granite and dinas or other quartzites, were better suited for withstanding the corrosive action of metals and slag at high temperatures. In the case of the cupellation of argentiferous lead and the fine burning of the silver, recourse was made to bone ash,—the product obtained from grinding bones, washing away the impurities and burning the residual calcium double phosphate. An improvement was made in the first types of open-hearth furnace by using a lining of silicious clay, which paved the way for the introduction of bricks made from the grinding of very silicious rocks and bonding with a small percentage of lime or plastic clay. The first raw materials used for this purpose were the dinas rocks found at Dinasfels in Glamorganshire, and ganister found beneath the coal beds near Sheffield in England, and near Düsseldorf in Germany; other favored materials were the Kieselschists found in especially fine quality in Silesia. Some of the blown sands found near the old Welsh smelting works carry some 4 or 5 per cent of lime in the shape of minute fragments of shell sand. These produced a partial fritting of the sand when this was used as a bottom for reverberatory furnaces.

From the earliest time considerable care was exercised in selecting suitable sands for casting moulds. Kampmann in *Annales des Mines* gives the following analysis of sands employed for fine casting and states that a good sand for moulds may be artificially made from a mixture of 93 parts fine quartzose sand, 2 parts red English ochre and 5 parts of aluminous earth as little calcareous as possible.

Composition of Various Casting Sands

	I.[1]	II.[2]	III.[3]	IV.[4]
Silica	92.083	91.907	92.913	90.625
Oxide of iron	2.498	2.177	1.249	2.708
Alumina	5.415	5.683	5.850	6.667

[1] Sand from the foundry of Freund at Charlottenburg.
[2] Sand employed at Paris for bronzes.
[3] Sand from Manchester.
[4] Sand from the establishment of Lagua near Stromberg.

The sand used at the works of Count Stolberg-Wernigerode in the Hartz Mountains, famous for its bronze and iron monuments and large but fine castings, consists of a mixture of dried and dehydrated argillaceous sand, and sand from solid sandstone in the proportions following: 1 part common argillaceous sand, one part alluvial sand and 2 parts sandstone sand. The analysis of this mixture showed 79 parts silica, 13.7 of alumina, 2.4 protoxide of iron, 0 of magnesia and 4.6 of potash. Analyses of some of the famous Japanese casting sands show similar compositions.

With the development of the porcelain industry attention was drawn to the refractory character of the kaolin and other highly aluminous clays. The potteries of Germany and France proved the value of these high-grade clays in the use of crucible and furnace brick. The early metallurgist, Berthier, learned the importance of applying these clays for the manufacture of metallurgical furnace brick. Close following the introduction of aluminous brick came the realisation of the value of graphite as material for crucibles and furnace linings. It is interesting to note that a patent

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No. 767, Jan. 25, 1762, was granted to William White for a "new invented manufacture of crucibles for the melting of metals and salts." The specification directs that Stourbridge and Dorsetshire clay are to be mixed with Woolwich sand and water and that the mixture is to be trodden with the feet. The use of coke in admixture with Stourbridge clay in the manufacture of crucibles was patented by Anstey, who used two parts of fine ground clay with one of pounded gas coke, and prescribed that the coke was not to be crushed finer than one-eighth of an inch, and that the mixture should be worked with water and well trodden. Anstey's pots withstood eighteen successive fusions of cast iron provided they were not subjected to frequent and rapid cooling, and earned for him from the Society of Arts a silver medal and the sum of 20 guineas. It was not long afterward that an effort was made to substitute plumbago for coke, and in 1828 Mr. Charles Sidney Smith was awarded £20 for the manufacture of crucibles composed of Stourbridge clay, coke and plumbago. The process of making these pots of crucibles is described in Vol. 47 of *The Transactions of the Society of Arts.* They seem to have been of an even homogeneous character and of considerable strength and refractoriness.

In 1856 Deville made alumina crucibles from a mixture of gelatinous alumina with a proper proportion of calcined alumina and from an intimate mixture of equal parts of alumina and pounded marble. These crucibles when exposed to high temperatures acquired a remarkable degree of solidity and resisted sudden and great changes in temperature. In 1869 bauxite, which had been previously analysed by Berthier, was suggested as a raw material for crucibles. It derives its name from the hill called "Colline des Baux," from which Berthier obtained his sample. Some bauxite in Andalusia had been used by the Moors for the manufacture of terra-cotta ornaments, but it was not until the end of the '60's that it was used as a lining for furnaces. It is not surprising, considering its physical properties, that it has not attained a wider application for this purpose.

Lime crucibles were made at this time and Deville conducted experiments in applying them for smelting. On account of the reaction of lime with carbon and its tendency to slag with any silicious or aluminous material, it did not find a wide field of use. Furthermore, the lime crucibles disintegrate when kept for a long time and are unsuited for the melting of iron or iron ores on account of the tendency to form calcium ferrate. Magnesia, on the other hand, soon obtained wide and favorable reputation as a refractory lining and was used as far back as 1870 in Bessemer converters and open hearths. Since that time it has steadily grown in favor and is to-day perhaps the most favored of all refractories.

Hardly less useful than magnesite is dolomite, which has been favored by the English and German iron masters as a lining for open-hearth furnaces and Bessemer converters. Unburned limestone, when mixed with clay, has been used as a lining in more recent years to replace the old-fashioned bone ash and marl, both of which were used in the eighteenth century, but it, in turn, has given way to magnesite. It is only within recent years that the high-grade magnesite bricks manufactured from Grecian and Styrian deposits have obtained the high reputation they now deservedly enjoy.

Within the last twenty years chromite has been used as a refractory material and the linings of many furnaces have withstood long sieges owing to the assistance which chromite brick lent. This is effective when used along the slag line, as a buffer layer between the magnesite bottom and the fire-brick foundation, or between the magnesite lower, and fire-brick upper, furnace walls. Thus chromite prevented the possible agglomeration or fritting of these two materials together. The use of steatite (magnesia and alumina silicate) is a comparatively modern innovation, used principally in electric furnaces.

Carborundum fire sand enjoys widespread use both as a protective paint for preserving bricks against acid fume and slag and also in the form of bricks composed of a mixture of fine carborundum sand with a small quantity of fire clay or lime. Another realm of refractories is found in the metals, particularly iron, both cast and wrought, nickel, gold and platinum. Cast-iron kettles wear exceedingly well provided they are not exposed to high or sudden changes in temperature. They are especially useful in the refining of argentiferous lead by both the Parks and Pattinson processes. For certain purposes crucibles of cast and wrought iron are economical and efficient. Platinum finds its greatest use in the chemical laboratory for holding slags and mixtures which are subjected to high temperatures in fusion, and in the form of kettles for holding 60° sulphuric acid in the process of refining. Finally, the manufacture of asbestos mixtures has enabled us to develop in recent years the application of insulating and protective covering, and the electric furnace has promoted the manufacture of alumina, magnesia and calcium-oxide ware.

THE DEVELOPMENT OF THE REFRACTORY INDUSTRY IN THE UNITED STATES

The developments in the refractories industry within recent years have been remarkable. Thirty years ago this industry in the United States produced products to the value of $400,000 a year. Now the annual value of refractory products is between fifteen and twenty million dollars.

This is altogether due to the progress made in the metallurgical industry. The wealth arising from this industry would have been impossible of realisation had it not been for the energy of the refractory makers in supplying durable materials to stand severe physical and chemical strain. In 1820 a blast furnace made 80 tons of iron a week, in 1860 about that much per day, now it makes 500 tons daily. In 1880 a copper furnace would smelt 20 to 30 tons of ore per day. Now it handles as much as 1500 tons. Coke-oven, blast-furnace and cement-kiln developments are only a few of a similar character. The refractories industry has amply proved its ability to cope with these new demands. One firm alone in America produces over 1,000,000 refractory bricks a day. There are about 400,000 silica and 50,000 magnesia bricks produced daily in the country.

But it is in quality as much as in quantity that the refractories industry has met the demands made on it by the enormous furnaces, stoves and ovens. And, to its credit, it has generally been first in anticipating these wants and has frequently educated the operators in the requirements of good, modern practice.

The growth* of the fire-brick industry depends largely on other kinds of manufacturing in which the conversion of the raw material into the finished product has to be accomplished by great heat, and this is done in furnaces or other receptacles which must be lined with some refractory material. Large quantities of fire brick are, therefore, required in smelting operations. The clay industry, with its brick and pottery kilns, requires a large number, as also the Portland cement industry, the coking industry and many others. Some of these, like the iron industry, were in operation before fire brick were available, and sandstone blocks were used as furnace linings.

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* Ries and Leighton, "History of the Clay-Working Industry in the United States," pp. 38–43.

New Jersey seems to hold the honor of being the first producer of fire brick in the United States, for they are said to have been made there in 1812, although the location of the original plant is not known. It is definitely known, however, that in 1825 the Salamander Works of Woodbridge, N. J. (no longer standing), were in operation. These were followed by the erection of a factory by John Watson in 1833, which remained in operation for a number of years. It is also stated that fire bricks were made in Florida and shipped to New Orleans in 1827, and that stove linings were made in Connecticut about 1835.

According to Mr. McClave refractory bricks were being produced in Toronto, Ohio, in 1830, but the industry was probably only temporary, for later the Ohio furnace men appear to have been shipping in most of their refractory wares from New Jersey and Maryland, until in 1869 they were supplanted by those made at Sciotoville.

A permanent plant was first developed when fire-brick works at Queen's Run commenced operation in 1836. This subsequently became the firm of Fredericks, Monroe & Co.

It was in 1837 that the famous Mt. Savage, Md., fire clay was discovered, and two years later the Union Mining Company began operations which have continued up to the present. In some publications these are incorrectly stated to be the oldest fire-brick works in the United States. About this time the Lower Kittanning plastic clay and the flint clay of Clarion County, Pennsylvania, were being worked by S. Barnes & Co., of Rochester, Pa., who appear to have started one of the earliest fire-brick works in that state. They were followed in 1842 by James Glover who discovered the Bolivar fire clay at the place of that name and ran a small fire-brick factory. He took his bricks to Pittsburgh by boat, and after some difficulty succeeded in disposing of them. So well were they liked that the bricks soon won a reputation, and Bolivar to this day is one of the important fire-brick-producing localities. The industry continued to develop rapidly, and we find factories starting operations in different states, especially if there was a chan oduct, which in those days commanded a much higher price than now.

In the year 1845 another yard was established in the Woodbridge district of New Jersey, viz., that of Berry & Son, with others following it; among these being Sayre & Fisher, Sayreville, 1868; H. Maurer & Son, Maurer, 1856; M. D. Valentine & Bro., Woodbridge, 1865; and others. Kier Brothers of Salina, Pa., began in 1845.

The fire-brick industry was, however, slow in moving westward in its development, for it was not until 1846 that it began in St. Louis with a small factory located on Gravois road. This is no longer in operation. The oldest of the present plants are those of Evens & Howard and the Laclede Fire Brick Company, which were established in 1855. St. Louis with its great deposits of carboniferous fire clays and markets in the Central and Southern States was destined to become an important center of fire-brick making, and other factories were opened later, among these being the Christy Fire Clay Company, in 1857, and the Parker Russell Company, in 1866. The Christy and Laclede companies have since been consolidated. Another refractory asset which has helped to make St. Louis famous was its deposits of clay for glass-pot and zinc-retort manufacture.

In New York the making of gas retorts commenced in 1854 and spread to other states, but the production of these is not as great as formerly.

Fire bricks were being made at Steubenville, Ohio, from 1854 to 1858, and the industry was started in Illinois not later than this. In 1859 Soisson & Co. of Connellsville, Pa., established their works at that place, and three years later, in 1862, fire-brick manufacture began at Bath, S. C., but has never become of importance. At Pittsburgh the Star Fire-Brick Works commenced operations in 1865, and three years later the industry was commenced at Canal Dover, Ohio.

The fire clays of the far West developed at a comparatively early date, those around Golden, Colo., being discovered in 1866. The deposits, however, which have made the district rank foremost among the western producers were not opened until later. The fire bricks which were then made and which are still being produced at Denver, Pueblo and Cañon City are much used throughout the Western States and have earned a good reputation, even though they have to compete with the bricks made in the Mississippi Valley district.

The fire clays of Lewis County, Ky., were mined as early as 1871 and used for making fire brick in Cincinnati. In the same decade we note the building of works at East Portsmouth, Ohio, in 1870, at Woodland, Pa., in 1871, and at Retort and Manorville, Pa., in 1872.

West Virginia was late to arrive in the line of fire-brick producers. The Kittanning clays of Hammond, Marion County, being one of the earliest deposits opened were worked in 1876. However, the industry has progressed favorably since then.

By the year 1880 the fire-clay-manufacturing industry had assumed wide and strong importance in many states, notably Ohio, Pennsylvania, New York, New Jersey, Indiana and Missouri. Several important additions occurred in the 80's, as at Canal Dover, Ohio (1880); South Webster, Ohio (1883); Queen's Run, Pa. (1883); Portsmouth, Ohio (1888); Wallaceton, Pa. (1888); Strasburg, Ohio (1889); there were still, however, several important but not necessarily large districts. In 1882 the tertiary clay around Holly Springs, Miss., was attracting attention, and two years later, 1884, the Kentucky fire clays were worked at Amanda Furnace and Bellport Furnace, and in 1886 by the Ashland Fire Brick Company, at Ashland. In 1895 the Olive Hill Fire Brick Company of Olive Hill, Ky., began using the carboniferous flint clays, but it is not known how long previous to this these had been developed.

Developments continued in Pennsylvania and Ohio, and new works were continually springing up. They included those at Phillipsburg, Pa. (1893); Clearfield, Pa. (1894); Beech Creek, Pa. (1900); and still later those at Figart, Pa. (1901), and Strasburg, Ohio (1904).

The Dakota clays of Colorado, previously mentioned as occurring at Golden, were further developed at Cañon City, in 1900, and since then at other localities. Later developments took place also in Utah, Montana and South Dakota, but no definite data are available regarding them.

After reviewing what has just preceded, one cannot help but be impressed by the great and steady development of the fire-brick industry in the carboniferous areas of Ohio, Pennsylvania, and, to a lesser extent, Kentuck [illegible] d West Virginia.

The product not only finds a ready market in the districts of production, but is shipped to many states in which high-grade refractories are manufactured sparingly or not at all.

There are a number of small works making fire brick and stove linings, which are located at points some distance removed from the fire-clay districts, which supply the raw clay. Not a few are located in the New England States.

It is needless to say the growth of the fire-brick industry has been attended by improvements in the methods of manufacture, not so much perhaps in the machinery used, although the production of machine-moulded brick has increased, as in the compounding of proper mixtures, which will best individually withstand the conditions of use to which they are subjected. With the same object in view the manufacturers have also developed a great variety of shapes for special purposes. Some firms have likewise succeeded in making many interesting products of astonishingly high refractoriness.

In addition to the firms already named, mention should be made of the incorporation in 1902 of the Harbison-Walker Refractories Company with headquarters at Pittsburgh, Pa., and of the formation of the American Refractories Company in 1906 with offices in Chicago.

Most of the works of these companies make fire-clay bricks. The Chester, Pa., plant of the Harbison-Walker Company makes nothing but magnesia and chrome bricks from imported materials. The Mount Union, Pa., Layton, Pa., and the East Chicago plants of the same company produce silica bricks, while magnesia and silica bricks are made at the Joliet plant of The American Refractories Company.

For the manufacture of silica bricks a few special quartzites are favored, such as the pure and highly infusible deposits of Wisconsin in the neighborhood of Devil's Lake and Baraboo, and the quartzite of Clearfield and other places in Pennsylvania.

Bauxite is found in large quantity in Arkansas and other states, and is calcined and burned into a face brick. Magnesite, too, is found in considerable quantity in California, but all the refractory ware is made from raw or burned magnesite, imported from Greece or Austria-Hungary. Chromite brick is made in Europe and America from chrome ironstone, imported from New Caledonia, Turkey or Greece.

Special refractory ware, such as high-grade alumina, graphite, carbon and special mixtures of ingredients for particular purposes, is also made in the large and well-equipped refractory works in America, and to a less extent in England, Germany and France.

The manufacture of hollow ware, such as retorts, crucibles, muffles, etc., and the special industries making the artificial carbon-silicon and the graphite ware are in the control of firms distinct from the refractory brick companies.

CHAPTER I

CLASSIFICATION OF REFRACTORY MATERIALS

MATERIALS used in the walls, hearth, roof and lining of hearth furnaces, in the walls, boshes, crucibles of shaft furnaces, in retorts, in crucibles, flues and all parts of a metallurgical or chemical plant exposed to the action of heat, must have the property of sustaining high and changing temperatures, the action of the atmosphere and of the slags, the metal product and the flame to which they are exposed without suffering sudden physical or chemical change. The increase in the quantity and variety of refractory materials has been due to the fact that different processes demand different properties in the materials, and that while one refractory material may give high satisfaction in a furnace used in one branch of smelting, roasting or refining, it may be quite unfit to withstand the influences, physical and chemical, which would be produced if another smelting method or other temperatures were to be used in the same furnace. Generally speaking, it has been found that the character of the slag produced in a particular process determines the type of furnace and kind of material that should be used, once it is granted that the refractory material must be able to sustain the effect of high temperature without decomposing or suffering considerable physical change, such as cracking, splitting or peeling. Of course it is understood that while some materials can endure a medium temperature, say of 1000° C., they would have to give place to other materials of the same general class of physical and chemical refractoriness, which would be able, however, to stand high temperatures such as 1300° C. and above if these were to be used.

Dividing our list of refractories into classes we find that reactions producing acid slags demand refractories of an acid character; basic slags call for furnace materials of a basic character; neutral materials are often used in both basic and acid processes, but, as a rule, may be regarded as replacing basic materials when exceedingly strong resistance to chemical action is demanded of the furnace lining.

It is plain that when a slag is acid, that is, when its basic content is more than satisfied with silica or with silica and alumina, there will be little danger of this slag extracting any more silica or alumina from an acid brick lining. By "acid," when applied to refractory materials, we understand a material having for its chief constituents both silica and alumina or silica alone. In the same way a slag containing more ferrous oxide than is required to slag the silica will not be likely to attack a basic furnace lining containing calcium and magnesium oxides in the form of burned dolomite. And neither the silicious slag nor the basic slag would have any ill effects on a refractory neutral lining such as ferrous chromite.

The chemical constituents of a slag and of a heated furnace material are always endeavoring to form salts of a neutral character. Thus a bisilicate slag containing one or two bases, such as lime and ferrous oxide of the composition $ROSiO_2$, would make an effort to form a singulosilicate of the composition $2\ ROSiO_2$ and would demand an acid lining since otherwise it might extract some of the base from a basic lining. Vice versa, a slag that was already basic, say $4\ ROSiO_2$, would extract some silica from a silica brick lining to form $2\ ROSiO_2$, a more neutral slag. To avoid such contingency a neutral or basic lining should be used. The fire clays have been especially useful for making fire-brick linings since they approach the character of neutral salts, namely, silicates of alumina; although it is true that, under certain conditions and with certain metallic oxides, the alumina and silica both act as acids and are easily corroded by certain basic slags, such as, for instance, the oxides of lead, bismuth and antimony.

For general metallurgical purposes quartzite materials and the more infusible clays are in widest use. The physical qualities of clay make it very attractive to a furnace operator and metallurgical mason. Owing to its general occurrence in nature in different varieties, no matter how or where located the metallurgist will nearly always be able to obtain the various kinds which make the best mixture in plasticity, tenacity and fusibility for his purposes. As a rule the more infusible or hard flint clays are not plastic. On the other hand the soft plastic clays are apt to be of low fusion point, but it is only by an admixture of about 25 per cent of the more fusible plastic clays that we are able to work the more refract [illegible] into bricks or into mass suitable for use in furnaces. The common adobe clays or muds, high in lime, and other alkalis or alkaline carbonates obtain very wide use in a smeltery and save the use of the more expensive clays for plugging tap holes, making breasts and, in dry climates, for making sun-dried bricks for various purposes where infusible qualities or tenacity are not demanded. We class the clays in the following system as acid material for the reason that they may be only used for processes in which acid or neutral effects are produced. For instance we may not use fire bricks of the most refractory kind in the metallurgical furnaces which produce oxides of the metals nor may we use them in the linings of the basic open-hearth furnaces where the material would be eaten by the ferrous oxides and other basic oxides produced. On the other hand pure alumina like calcined bauxite (Al_2O_3) does act as a basic refractory and may be used for so-called basic processes. The strongest and most highly acid material is quartzite used either in the form of silicious rocks or in the form of bricks or loose material in linings. The most useful of the strictly basic materials

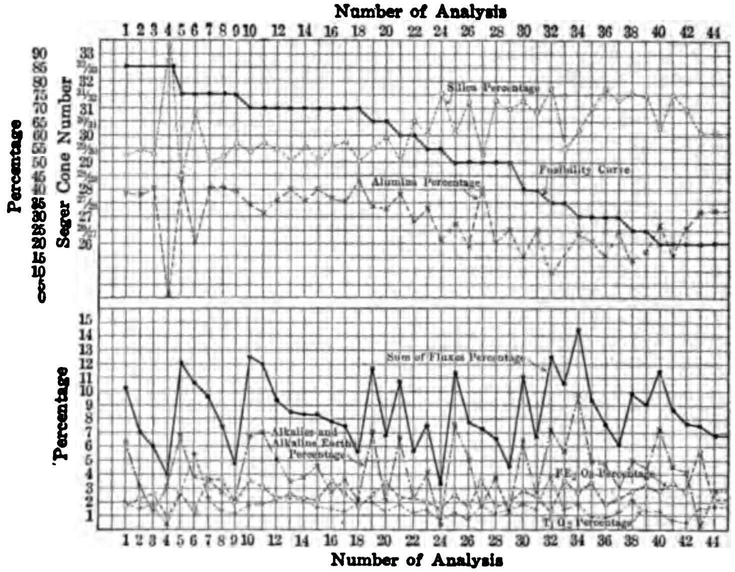

FIG. 5. — Graphic Representation of Composition and Properties of American Fire Brick.

is magnesia, the product of the burning of magnesium carbonate; while "dolomite," by which, in furnace lore, we mean burned magnesium-calcium carbonate, has found a very wide application since the development of the basic Bessemer process and is also used widely in open hearths demanding a basic lining.

The whole range of refractory materials may be divided into the following classes:

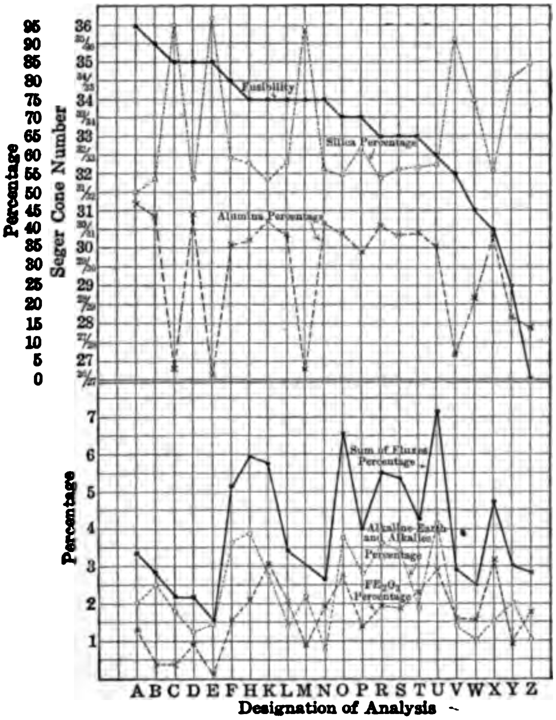

FIG. 6.* — Graphic Representation of Composition and Properties of European and English Fire Brick.

Acid Refractories. — Silicious materials depending on the infusibility of pure silica. The materials must then be high in silica and low in metal oxides and alkalis. These are used in the following forms:

(1) Natural rock; (2) Prepared mass; (3) Burned brick; (4) Electrically fused quartz.

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* See Weber, *Transactions Am* [illegible] *ining Engineers*, Sept., 1904.

Aluminous-silicious materials, which depend for their refractory qualities on the relative infusibility of the salt, alumina silicate; but little free silica may be present, since it lowers the temperature of fusion. These also are used in the three forms: (1) Natural rock; (2) Prepared mass; (3) Burned brick.

Basic Refractories. — Materials of pure, or nearly pure, alumina, used in the form of mass and of brick, such as calcined bauxite and alundum.

Materials consisting of the oxides of calcium and magnesium, used in the form of mass or of brick. Among these oxides are included lime, dolomite, magnesite, bone ash and marl.

Neutral Refractories. — Materials of relatively infusible mineral salts, such as steatite, chromite and possibly cement, used in the form of mass or of brick.

Natural and artificial carbonaceous materials, such as charcoal, coke and graphite, in the form of mass and of brick.

The artificial carbon-silicon compounds, such as carborundum and siloxicon, or, as they are also known, crystalline and amorphous crystolon.

The metals, iron, platinum, nickel, etc.

The asbestos refractory batches and paints.

This classification is made with consideration of the chemical properties of the materials. The property of fusing only at high temperatures is essential to all refractories and this is influenced by physical qualities which have not been considered in the division made. In addition to the chemical analysis of a material it is necessary also to know its strength, modulus of expansion at high temperature, density, specific gravity, porosity, capacity to absorb water, the size of the contained grain, its coefficient of heat conductivity and, in the case of clays, its degree of plasticity and adhesiveness. The testing of refractories is an important subject and demands a special chapter.

CHAPTER II

THE RELATION BETWEEN SLAGS AND REFRACTORY VESSELS AND LININGS

A KNOWLEDGE of the physical chemistry involved in the temperature of formation of silicates, and other less frequently occurring metallurgical salts, is useful to the engineer who intends to construct furnaces or to prepare refractories. The chemistry of the reactions between acids and bases in metallurgy is relatively simple since the number of acids is limited to two or three. Of these the chief is silica, SiO_2, which, in the anhydrous state, becomes an active acid only at fairly high temperatures. On the other hand the hydrosilicic acids, ortho-, $2\ H_2O.SiO_2$, and meta-, $H_2O.SiO_2$, behave like the ordinary hydrous acids, such as sulphuric, $H_2O.SO_3$, and are active at ordinary temperatures in attacking and decomposing salts, particularly those containing such bases as the alkalis, alkaline earths, ferrous oxide and manganous oxide. Practically all slags formed in metallurgical smelting operations, as well as all silicate minerals, are salts resulting from these attacks. For instance, in mineral formation calcium carbonate on being attacked by metasilicic acid, $H_2O.SiO_2$, forms the mineral wollastonite, $CaSiO_3$, and the carbonic acid and water go off as H_2CO_3. In iron-blast-furnace smelting, the flux, lime rock, $CaCO_3$, on reaching the zone of fusion, along with the silicious ore, forms a bisilicate slag, $CaO.SiO_2$, which is for the greater part really the mineral wollastonite.

In the mineral world we have the formation of olivine by the attacks of orthosilicic acid, $2\ H_2O.SiO_2$, on dolomite and magnesium carbonate which may also contain ferrous and manganous salts. The mineral class, olivine, includes such minerals as $2\ MgO.SiO_2$, forsterite, $2\ FeO.SiO_2$, fayalite, $2\ MnO.SiO_2$, tephroite, $MgO.CaO.SiO_2$, monticellite, $2(CaFe)O.SiO_2$, iron-lime olivine, and $2(MgFe)O.SiO_2$, olivine. These same minerals have been seen, in crystallized form, in lead-furnace slags, which are singulosilicates (orthosilicates) of lime and ferrous oxide with, often, magnesia and manganous oxide present. We do not work with sufficiently high temperatures in metallurgy to make slags of either dry silicic acid, SiO_2, or of alumina alone, neither do we make slags of the alkaline earths. Consequently, these are resistant or refractory to molten salts containing the same or similar materials in excess; for it is almost as much a fact that a slag high in silica will not attack a silicious lining, as that a slag high in bases will not attack a basic lining such as magnesia, if its physical properties are such as to permit its use at the temperature employed. However, we have then to consider in a refractory lining not only the chemical indifference to the material fusing in the vessel, but also its resistance, in both a physical and chemical sense, to the effects of high temperature. We demand certain physical qualities in our refractory. If we are heating some oxide, salt or metal in a crucible from an exterior fire, the crucible should, if possible, be made of a material which conducts heat rapidly. If we are heating a bath of such substance in a furnace, we should demand that the furnace lining be an insulator, or a poor conductor of heat. When we leave the explored realm of the rock silicates, such as sandstone or granite, or the alumina silicates, such as clays, and commence to use straight basic oxides as refractory materials, we face the well-known laws that a metallic oxide always has both a high modulus of heat conductivity and physical instability at high temperatures. How these laws are circumvented is discussed in various chapters. Suffice it to say that the silica-alumina and silica refractories have enjoyed more than their due usage because of their satisfactory physical conduct at high temperatures. A base is always eager to pair off with silica and silica is equally anxious to go into the salt condition unless it be restrained by its greater affinity for a base with which it may be already combined. With certain relative quantities of bases and silica present we may effect the formation of a salt with a desired degree of silicification. According to the degree of silicification the salt is known in metallurgy as a subsilicate, a singulosilicate, a sesquisilicate and a bisilicate. In mineralogy we have subsilicates, orthosilicates and metasilicates, but no mineral classification corresponding to sesquisilicates. It is not, however, because no minerals of this silicate degree exist. The dividing line between ortho- and metasilicate lies at a relation of acid oxygen to basic oxygen of from $\frac{1.55}{1}$ to $\frac{1.70}{1}$.

Below this acidity the mineral will be classed as an orthosilicate. In a fused liquid mass of bases and acids, mineral components will group themselves into mineral entities and, if the slag is cooled slowly, these minerals will crystallize. Those with an acidity up to the dividing line mentioned will be orthosilicates, those above, metasilicates. Besides the crystallized minerals there will be much amorphous glass present, particularly if the slag has been chilled quickly. The effect of alumina is to reduce the quantity of silica required to divide the ortho- and metasilicates, since it acts both as a base and an acid itself. If no alumina is present a ratio of $\frac{1.70}{1}$ is the permanent line of division. The type of the minerals formed from fluid slag mixtures as well as its physical properties and the character of the slag or glass remaining depend on the kind of bases present. The particular base which predominates and the relative amount of calcium to femic (Mg, Fe, Mn) bases determine the class of minerals formed; whether, for instance, in metasilicates (bisilicates) we shall have augite, with approximately equal proportions of Ca and Fe, Mn, Mg present, hypersthene, with preponderating Fe, Mg, Mn, or wollastonite with excessive Ca, or whether we shall form slag on the border line of two of these classes and containing both. In the orthosilicates in a similar way we may have calcium olivine (melilite) separating with preponderating lime, and ferromagnesium or femic olivine (forsterite fayalite) with excessive ferrous and magnesium oxides. These mineral formations take place in slag at ordinary pressure.*

Classification of Silicates. — This classification is based on the relative amounts of oxygen in the acid and base radical of a salt. For instance, wollastonite is $CaO.SiO_2$ or $CaSiO_3$; this is also the composition of many iron-blast-furnace slags. There are 2 parts of acid oxygen to 1 of basic oxygen; the mineral is therefore called a metasilicate, the slag a bisilicate. If the oxygen relation were 1:1, as, for instance, in forsterite which has the formula, $2\,MgO.SiO_2$, the slag would be a singulosilicate and the mineral classified as an orthosilicate.

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* See Fulton's "Principles of Metallurgy," McGraw-Hill Book Company, chapter on slags, p. 245.

Ratio 0 in acid. 0 in base.	Formula.		Metallurgic nomenclature.	Chemical nomenclature.
	RO base.	R_2O_3 base.		
Less than 1	R_3SiO_5	R_2SiO_5	Subsilicate	
1	R_2SiO_4	$R_4Si_3O_{12}$	Singulosilicate Monosilicate	Orthosilicate
1.5	$R_4Si_3O_{10}$	$R_8Si_9O_{30}$	Sesquisilicate	
2	$RSiO_3$	$R_2Si_3O_9$	Bisilicate	Metasilicate
3	$R_2Si_3O_8$	$R_4Si_9O_{24}$	Trisilicate	
4	....	....	Quadrisilicate	

Now besides silicic acid we meet in metallurgy, but less frequently, the salts of the following acids: phosphoric acid, boric acid, the halogens, titanic acid, plumbic acid, bismuthic acid, antimonic and arsenic acids; also alumina and ferric oxide. At times some of these metal oxides act as bases, on other occasions which are rarer, as acids. Bismuthic oxide, for example, attacks linings of both silica and magnesia, forming respectively bismuthic silicate and magnesium bismuthate. The temperatures at which these slags form vary. As a rule the slags which have equal quantities of acid oxygen and basic oxygen, namely, the singulosilicates, have the lowest temperature of formation. Then the temperature required to form the slag and also that demanded to keep it fluid will rise both as the slag becomes more basic (subsilicate) and as it becomes more acid (bi- and trisilicate). Again the formation temperature of each class varies according to the base or bases composing it. All magnesia silicates are difficult to form and to keep liquid; iron silicates are much more tractable.

The temperature, at which the slag is formed by the combination of the bases with the acid, is, on an average, 200° C. higher than the temperature at which the slag will cease to flow or, in other words, the formation temperature is about 200° C. higher than the freezing temperature. This difference, however, is not constant. Certain minerals and slags are almost infusible at commercial furnace temperatures and may not be made with profit. Such are the aluminates of magnesium and zinc, known as spinels, which form at a temperature of about 1600° C.; some spinels freeze above 1500° C.

The base and the acid of the slag are alone relatively infusible; CaO melts above 1900° C. and SiO_2 at 1850° C. Now not only does a combination, whether singulo-, sesqui- or bisilicate melt at temperatures very much lower (for instance, $CaSiO_3$ melts at 1512° C.), but mixtures of silicate slags or minerals form eutectics. Thus $CaSiO_3$ melts at 1512° C., $MgSiO_3$ at 1524° C., but a mixture with 30 per cent of the latter and 70 per cent of the lime silicate melts at 1350° C. Furthermore, a silicate with more than one base fuses at a lower temperature than the one-base silicate. Ferrous oxide is particularly effective in lowering the formation temperature but more particularly the freezing temperature. For this reason it is an essential ingredient in slags made from silicious ores in large furnaces in which we aim to work at a low temperature whether for commercial or chemical reasons. When smelting in crucibles with small quantities of materials, alkali salts, such as sodium and potassium carbonates and sulphates, may be used to obtain similar effects. Yet it is seldom wise to make slag and salts which either have too low a temperature of formation or are too fluid when formed. The slag must form gradually and be sufficiently long in a state of pasty incipient fusion both to allow the agents, such as those of reduction and metallic oxides, sulphides and salts in the charge, to meet each other and react fully. Then the slag should be, by this stage of the process, sufficiently liquid to allow the heavy metallic products to settle. It is evident that if the temperature of formation is low the slag may form before sufficient heat has been developed to complete the reactions desired; if the slag is too fluid when formed it will not be sufficiently long in the pasty stage to hold the salts before they have suffered decomposition and, if the slag, in its final state, be too liquid it will wash out metallic value when tapped or poured from the vessel holding it. Nor may the slag in its final state be too thick or pasty. Even when the initial condition at formation is thick, it must quickly become thinner in order that the work in a furnace or laboratory may proceed satisfactorily. There must be an ample difference in looks between that of a slag running normally and the same when it is chilling. There must be sufficient margin between the temperature of formation and of freezing and such a different aspect between the normal and dangerously cold slag that the operator has time to change the constitution or the temperature before the slag freezes and closes the mouth of the furnace. In addition to all these qualities the slag must be reasonably light so that it may separate from heavier metallic substances. It has been found that the most satisfactory slags in smelting practice are in the singulo-, sesqui- and bisilicate classes, which are represented respectively by lead-furnace, copper-furnace and iron-blast-furnace slag.

A favored lead slag which fulfills the conditions mentioned consists of 16 to 26 parts CaO, 30 SiO_2 and 33 to 45 FeO; a copper slag will contain from 16 to 35 parts FeO, 10 to 30 CaO and 38 to 45 SiO_2; an iron-blast-furnace slag generally contains approximately equal quantities of CaO and SiO_2, of each about 45 per cent. Allowance is made in all cases for 10 parts impurities in 100 parts.

Refining slags of all kinds from open-hearth, reverberatory, converting and cupelling furnaces are in most cases basic or subsilicates. Assayers' crucible slags are examples of sesquisilicate salts of alkali bases along with silicic and boric acids.

It is very necessary for the engineer to determine and understand the nature of the slag, which is to be made, before he proceeds to construct his furnace. A lead-smelting furnace slag, for instance, is not completely satisfied with silica; it will extract this acid even from a fire-clay brick lining. Sulphides and arsenides produced in metallurgical operations, such as matte and speiss, which are the names given to the precious and base-metal-bearing sulphide and arsenide of iron, also react with the silica of the lining. Thus:

$$FeS + SiO_2 + O_3 = FeSiO_3 + SO_2.$$

The oxygen may be provided by some peroxide of iron present in the brick or by one of many other sources. Accordingly magnesia is preferred as a lining in crucibles of blast furnaces. It is, however, too expensive to use in the linings of settlers; these are removed whenever the settler freezes up, which may be a weekly occurrence. Sulphides penetrate into the brick lining rapidly and, in cooling and crystallizing, disrupt the brick. They also agglomerate so firmly to the surface that, in removing the matte from a settler, this will carry much of the lining with it. A dense material, especially when basic, is much less pervious to such attacks. The most resistant material is, however, water-cooled iron or steel in the form of jackets.

An excessively acid slag will attempt to go into combination with a basic lining and should be made in an acid-lined vessel. The physical properties must also be considered in determining the suitability of refractories for various purposes. Dense material and burned and vitrified products wear better than light porous and raw refractories, although these are often better insulators. We dare not insulate too thoroughly, as a rule, because in absorbing much heat the material undergoes many physical changes which render it less resistant, and it has been found wiser to waste some heat rather than to endanger the life of the lining.

The process of vitrification and incipient slagging in burning brick offers a field for investigation. An effort has been made to describe it in several of the chapters on the preparation of refractory materials.

The action of hydrous silicic acid on bases in forming silicates is illustrated in the reactions between the lime and sand in the manufacture of sand-lime brick. Lime, to the amount of 6 per cent, is added to sand, the whole is well mixed, moulded into brick at high pressure and steamed in a closed cylinder. The lime combines with a small proportion, possibly as much as 10 per cent, of the sand, and the calcium silicates formed hold the sand together and knit the whole brick firmly and homogeneously into a compact unit.

$$Ca(OH)_2 + SiO_2 = CaSiO_3.H_2O.$$

$$CaSiO_3.H_2O + Ca(OH)_2 = Ca_2SiO_4 + H_2O.$$

$$Ca(OH)_2 + 2\,SiO_2 = CaH_2Si_2O_6.$$

This same principle is applied frequently in metallurgy. We find examples in briquetting ores with lime, soda or water glass, and in making breasts and packings for furnaces with such mixtures as magnesia, fire clay and water glass which set and harden as the hydrous silicates form and bite the mass. These same hydrous silicates are probably formed in ore-sintering processes such as the Dwight-Lloyd.

Formation and Melting Temperatures of Silicates

Description.	Formation temperature.	Melting temperature.	Notes.
Europe.[1]	°C.	°C.	
Iron slag: 50% SiO_2, 17% Al_2O_3, 3% FeO, 30% CaO	1392	1208	
Lead slag: 36% SiO_2, 40% FeO, 8.5% Al_2O_3, 4% CaO, 3% MgO, 7.5% BaO	1220	1160	A dangerous slag because of the small margin between formation and melting temperatures.
Copper slag: 33% SiO_2 60.3% FeO, 7% Al_2O_3	1273	1166	
Syenite (Tharandt)	....	1130–1160	
Hornblende	....	1130–1166	
Mica porphyry	begins to fuse	1227	Some unmolten parts at 1452°C.
2 $Ca.SiO_2$	1570	....	Iron-blast-furnace slags
$(CaO.Al_2O_3)SiO_2$ $CaO:Al_2O_3::4:1$	1451	1367	
$(CaO.Al_2O_3)\ SiO_2$ $CaO:Al_2O_3::1:1$	1410	1203	
American slags.[2]			
Iron slag: 43.9 SiO_2, 8.6 Al_2O_3, 31.4 CaO, 10.2 MgO, 0.3 MnO, 4.5 FeO	1450	1250	Bisilicate
Lead-furnace slag: 31.47 SiO_2, 45.68 FeO, 22.85 CaO	1190	....	Singulosilicate
A possible copper-furnace slag: 40.80 SiO_2, 39.46 FeO, 19.74 CaO	1160	....	Sesquisilicate

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[1] From Vogt, Die Silicat Schmelzlösungen.

[2] Determinations made by H. O. Hofman (see Peter's "Practice of Copper Smelting," p. 610).

Melting Points of Refractories[*]

Substance.	Melting point.	
	°C.	Cone.
2nd-class fire brick (clay)	1400–1650	
1st-class fire brick (clay) above	1560	Seger cone 18
Pure kaolin ($Al_2O_3.2\,SiO_2$)	1830	Seger cone 35
Clay slate ($Al_2O_3.2\,SiO_2$)	1850	Seger cone 36
Alumina (Al_2O_3) softens at[1]	1970	Seger cone 42
Magnesite (dead burned magnesite) softens at about[2]	2500	
Chromite (burned chrome iron ore) softens below	2000(?)	
Lime (calcium oxide) softens below[3]	2500	
Silica (SiO_2) softens below[4]	1830(?)	Seger cone 35
Silicious natural rocks (sandstone, granite, gneiss, quartz porphyry, etc.) melt below	1600–1800	
The more basic rocks melt at lower temperatures. Syenite from Tharandt, for instance, melts below	1150	
Silica bricks soften at	1750 to 1800	
Magnesia bricks soften at	2000	
Carborundum decomposes at[5]	2220	
Carbon becomes pliable at	1900	
plastic at	2500	
boils at	3700	

[*] Authorities: Kerl, *Die Thonwaarenindustrie;* Wright, *Electric Furnaces;* Goodwin, *Transactions American Electrochemical Society*, p. 89; Lampen, *Journal American Chemical Society*, VIII, p. 852; Stansfield, *The Electric Furnace*, p. 50.

[1] Al_2O_3 melts at 2100° C. (Stansfield.)

[2] Magnesium oxide commences to soften at 1910° C.

[3] Calcium oxide commences to soften at 2040° C.

[4] Pure quartz melts at 1700° C. (Lampen: low.)

[5] The formation temperature of carbide of silicon is 1600° C. It crystallizes at 1950° C, and decomposes into graphite and silicon at 2220° C.

The silicon carbide oxidizes slowly at high temperature in the presence of air.

Silicon oxidizes when heated above 1470° C.

CHAPTER III

THE PREPARATION OF THE SILICIOUS REFRACTORIES

Refractory Natural Rock. — Some natural rocks of the older formations formerly played an important rôle in the construction of furnaces. They were roughly hewn, laid with the planes of cleavage at right angles to the bath of metalliferous matter and pointed with a refractory mortar of fire clay, or of ground quartzite mixed with lime or with fire clay. Pudding-stone, ganister, granite, gneiss, greywacke and sandstone were all used in the construction of reverberatory furnaces for the treatment of lead and copper ores and residues, in the crucibles of blast furnaces and in flues. For smeltery dust chambers and flues they were particularly well suited, and to this day may well be used when found in sufficient and readily accessible quantities. This natural rock is almost absolutely proof against the attacks of acid fume, and withstands the combined action of weather on the outside and of heat and acid on the inside. Pure silica, pure alumina, and silica and alumina together in the proportions which constitute a bisilicate mineral, are all highly infusible. Contents of lime, soda, potash, magnesia, oxides of metals and free silica reduce the melting point. Granite with 74 per cent silica, 16 per cent alumina and 10 per cent alkalis and metal oxides is only moderately refractory, because of the fluxing action of the alkali and metal oxides, and in an otherwise pure silica-alumina rock any silica in excess of that required to make a bisilicate slag acts as a fluxing agent.

The purest and most refractory of the silica rocks is ganister, a quartzite with about 96 per cent silica, which was found originally under the carboniferous beds in Yorkshire, in the beginning of the nineteenth century, by Mr. Weston Young. This Yorkshire ganister suffers from a small content of lime, which, while helpful in making artificial bricks, lowers the melting point of the mineral. It is seldom, however, that natural rock is used at temperatures sufficiently high to melt it. Sandstone and pudding-stone with about 90 per cent silica melt at 1600° C., granite, gneiss and quartz porphyry, with 90 per cent silica and alumina combined, at about 1700 to 1800° C. These rocks suffer more from physical than chemical disintegration when in the furnace. The natural rocks, especially ganister and dinas, expand considerably at high temperatures, and burst when subjected to sudden changes in temperature. They split and crack, unless most carefully and gradually heated, and may be the cause of loss of furnace charges. Again, large blocks are not as easy to handle as the smaller and lighter artificial brick. For these reasons the use of artificial refractory silica and fire-clay brick has superseded the application of the natural rocks. These played an important rôle, however, up to the beginning of the nineteenth century, when Mr. Young introduced the manufacture of silica bricks and advances were made in the methods of preparing fire-clay bricks. Even in the last decade of the nineteenth century there were still in use in Germany and in other parts of Europe reverberatory furnaces, for the smelting of copper and other ores and middle products, in which the foundations and side walls were made of solid blocks of granite. The unburned quartzite rock is still much used, when crushed and mixed with fire clay, as a lining of converters. This crushed silica rock with about 96 per cent SiO_2 is known as "ganister" in the trade and may contain considerably more impurity than the rock which is intended for the manufacture of silica brick.

Silica Bricks — Ganister, Dinas and Quartzite. — These terms are used with different meanings in Europe and America.

The original ganister was a dense, clay-bearing, carbonaceous sandstone of gray, gray-brown or red color, which occurred under the coal measures near Sheffield in England, Dowlais in Wales and in parts of Scotland. The ganister stone from the Lowood mine was found in a bed 10 feet thick at a depth of 1000 feet, and was considered especially valuable for brickmaking purposes in the early days of the manufacture of silica bricks. This ganister was bonded by means of the contained clay impurities and could be formed, dried and burned into a brick of fair quality without the admixture of extraneous bonding or fluxing agents. Later in the process of the development of brickmaking the supply of the original natural ganister rock was consumed, lastic fire clay was admixed with ground quartzite rock in the manufacture of the brick which still bore the trademark of "Ganister Brick."

"Dinas," on the other hand, was the name given to the sandstone which was found above the lime measures in the Vale of Neath, Wales, by Mr. Weston Young, the pioneer silica brickmaker who mixed the sandstone and limestone together and made silica bricks with the natural lime bond, from the beginning to the middle of the nineteenth century. His process was imitated. Quartzite and sandstone were ground and mixed with limestone which did not occur with the silicious rock but was especially quarried for the purpose, and from the mixture the dinas-silica brick was made.

These dinas bricks achieved a reputation for strength and infusibility, which carried them all over the world and resulted, in later years, in the establishment of quarries and factories in Germany, America and other countries for the production of the silica brick with lime bond. The standards of this lime-bond silica brick were easily set and maintained. The content of silica should be about 96 per cent, of lime from 1.2 per cent to 2 per cent and of alumina and iron about 2 per cent. The original quartzite should have 96 per cent silica and above, and not more than 2.5 per cent alumina and iron. The alumina should be present in the form of kaolin and not as a constituent of mica, feldspar or other alkali-bearing minerals. The content of alkalis should be low, not above 0.2 per cent.

Curiously, the name "dinas" was maintained in Germany, but discarded in America, where the name "ganister" was given to the lime-bond silica bricks. The clay-bond silica bricks, which were called "ganister" in England and "German dinas" in Germany, became "quartzite" brick in America, and in this class were included all brick having 70 per cent and above silica and the rest clay, or clay mineral substance. Now the silicious rock which is used in the preparation of lime-bond silica (the American ganister) brick may be quartzite or sandstone.

The two most important deposits of silica rock or ganister, as it is commonly termed, in America are in the Mt. Union district of Pennsylvania and in the Baraboo quartzite region of Wisconsin. The former is a fine-grained, yellow to white sandstone underlying an overburden of worthless conglomerate, while the Wisconsin quartzite is found in mighty bluffs of sedimentary splinter-grained vitrified rock, white, translucent at the edges, and but slightly discolored in the mass by a small percentage (under 1 per cent) of iron.

The following analyses show the composition of the different quartzites used in making brick.

A. — Dinas:

	Sheffield.	Dowlais.	Perth.
	Per cent.	Per cent.	Per cent.
SiO_2	94.40	93.05	98.31
Al_2O_3	4.21	4.23	0.72
Fe_2O_3	0.70	0.80	0.18
CaO	Trace	0.26	0.22
MgO	Trace	Trace	.....
Alkali	Trace	.....	0.14
Loss on ignition	0.69	1.00	0.35
	100.00	99.79	99.92

B. — English Ganister:

	Gartcosh (Scotland).	Sheffield.
	Per cent.	Per cent.
SiO_2	87.06	88.56
Al_2O_3	11.24	10.16
Fe_2O_3	0.69	0.97
CO	Trace	0.04
MgO	Trace	.....
Potash	0.61	.....
Soda	0.33	
	99.93	99.73

The American ganister is generally a sandstone or quartzite, of sedimentary formation, with about the following average composition, which is derived from analyses:

	Hollidaysburg, Pa.	Mt. Union, Pa.	Baraboo, Wis.
	Per cent.	Per cent.	Per cent.
SiO_2	98.43	97.5	98.00
Al_2O_3	0.60	1.0	0.75
Fe_2O_3	0.57	0.8	0.70
Water	0.29 CaO	0.2	0.01
	MgO		0.02
	99.89	99.50	99.48

In France a rock called "G [illegible] the cretaceous formation of the Ardennes [illegible] re of quartzite brick. It has about 80 per cent SiO_2, some alumina, iron oxide, lime and magnesia.

The English quartzite is light gray, translucent at the edges and has the fracture of crystalline quartz. The original dinas bricks are almost pure white, with a tinge of yellow; they show no surface cracks or crevices, and are covered with an even thin glaze. The fracture is fine-grained, showing a bright-yellow ground mass peppered with holes, brown flakes and pebbles of white or gray sandstone, but, nevertheless, the whole is a truly homogeneous mixture. The bricks are amongst the most satisfactory on the market. They are exceedingly infusible, and, like true silica brick, expand regularly at high temperatures, and are, accordingly, especially desired for the crowns of arches in reverberatory furnaces and coke ovens.

The following are some analyses of dinas and ganister bricks:

	A	*B*	*C*
	Per cent.	Per cent.	Per cent.
SiO_2	97.40	96.80	95.40
Al_2O_3	1.49	2.23	3.10
Fe_2O_3			.....
CaO	1.11	0.97	1.68
MgO	.....	.....	.....
Alkali	.....	.....	.....
Loss on ignition	.....	.....	.....
	100.00	100.00	100.00

A and *B* melt at Seger cone 34-35 (1800° C.).

(*A*, Allen, *B* and *C*, Lowood. *Thonindustrie Zeitung*, 1896, p. 25, and 1890, p. 4.)

European Dinas:

	D	*E*	*F*	*G*	*H*	*I*
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
SiO_2	92.95	92.85	94.03	97.03	95.1	95.6
Al_2O_3	2.76	1.46	1.83	1.14	2.0	0.25
Fe_2O_3	......	......	0.98	0.41	0.7	1.01
CaO	0.70	2.10	1.28	1.42	2.1	1.29
MgO	......	......	0.19	......	......	0.44
Alkali	......	......	0.47	......	......	0.38
Loss on ignition	......	......	......	......	......	......
	96.41	96.41	99.58	100.00	99.90	99.89

H melts at Seger cone 34-35 (1800° C.).

D, *E* and *F* Rhine bricks. *H* Silesian (Saarau).

I Italian (St. Antonio near Lusa).

G from Lütgen near Aachen.

American Dinas or Ganister:

	J	*K*	*L*
	Per cent.	Per cent.	Per cent.
SiO_2	93.93	96.00	94.00
Fe_2O_3	.79	1.14	1.05
FeO	.....	.....	.....
Fe	.55	.80	.73
Al_2O_3	3.07	1.12	2.65
CaO	2.55	1.69	2.30
MgO	.18	.12	.36
K_2O	.....	.12	Trace
Na_2O	.....	.....	Trace
	101.07	100.99	101.09

These did not melt at cone 30 (1730° C.).
J from Illinois, *K* from Pennsylvania, *L* from Missouri.

We have then to distinguish between three kinds of silica bricks:

1. Bricks of high silica content with admixed lime only as bond, known as English dinas, lime dinas or, in America, as ganister.

2. Bricks of somewhat lower silica content with admixed clay as bond, known in England as ganister, in Germany as German dinas and in America as quartzite.

3. Natural dinas bricks, moulded directly from the natural rock of mixed quartzite.

    a. Lime dinas, such as is found at Neath.

    b. Natural ganister, moulded from the mixture of clay and ganister found near Sheffield.

The ground mass of all is silica, which is used in the form of quartz, quartzite, sandstone, gravel and quartz sand to make bricks. All, with the exception of sand, are ground, mixed with lime or clay and moulded and burned to make brick.

Silica bricks, to be satisfactory, must meet the demands of:

1. Infusibility at highest temperatures employed in the industrial furnaces.

2. Strength after careful burning in kilns.

3. Small change in volume when employed in industrial furnaces.

The purer silica rocks are not all adapted to the manufacture of refractories. It is more the physical form than the chemical analysis which decides their value. Rounded pebbles of sand in a rock are a detriment; grains of splinter structure help to hold and lock the material firmly together. Further, coarse crystals of quartz and sandstone bands in shales or schists are disadvantageous. The more homogeneously knit together the particles are in the original rock, the more likely it is to be suitable for fire brick.

The value of a particular silicious mineral is determined by burning and observing carefully the change in volume and in strength of the original material. If the material expands and swells without cracking or weakening perceptibly, we may safely say that it is suitable for brickmaking.

Cramer examined * a series of quartzites by repeatedly heating them. The behavior of these, both in respect to change of volume and in cohesion, was very different. Some increased considerably in volume at the first heat, and relatively little thereafter; others expanded but little at first but showed a constantly increasing swelling in the later heats. Cramer used a temperature of fusion of cone 16 (about 1500° C.), in these experiments, and found a modulus of expansion varying in the first heat from 3.2 to 23.5 per cent.

The very pure coarsely crystalline quartzites fell to powder, consequently their modulus of expansion is lowest; the greatest expansion was possessed by the fine-grained, hard, tough quartzites, which retained their strength and showed the greatest contrasts in volume between the first and following heats.

The increase in volume is due: (1) to an increase in the size and number of the pores of the mass; (2) to an expansion of the mineral itself, and (3) to a transition of part of the mineral from a crystalline to an amorphous condition because of the change (to tridymite) of some of the quartz. To sum up, the most favorable condition indicating soundness for refractory purposes was the considerable expansion in the first heat and relatively small growth thereafter. For instance, a good dinas brick showed an expansion of 17.1 per cent at the first heat and only 22 per cent after the succeeding five heats.

The porous minerals, like sandstone and quartzite slates, behaved very differently. Some of the former broke up into powder at the first heat, others showed a continuous expansion up to the sixth heat and became gradually firmer and stronger. Cramer's test proved that the particular slate under investiga-

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* *Stahl und Eisen*, 1901, N. 14.

tion showed continuous expansion up to six heats and would expand if heated again.

Expansion of Some Silica Bricks in Linear Percentage

	Georgian dinas.	Natural sandstone.	Illinois ganister.	Pennsylvania ganister.	Missouri ganister.
	Per cent.		Per cent.	Per cent.	Per cent.
SiO_2	97.25	.....	93.92	96.00	94.00
Al_2O_3	2.0	.....	3.07	1.12	2.65
Fe_2O_3	0.64	.....	.79	1.14	1.05
CaO	0.07	.....	2.55	1.69	2.30
MgO	.....	.....	.18	.12	.36
Expansion 1st heat	4.02	2.59	1.57	2.90	1.90
Expansion 2d heat	5.15	3.13	Burned once at 1650° C.		
Expansion 3rd heat	5.44	4.22			
Expansion 4th heat	5.73	5.79			
Expansion 5th heat	6.20	7.39			

Pennsylvania ganister (*K* of page 35) expanded from 9.03 inches to 9.18 inches when heated to 1400° C. and contracted on cooling to 9.07 inches.

Physical Properties of Some Silica Bricks

Ganister brick made in	Crushing strength, pounds per square inch.		
	Side.	Edge.	End.
Illinois	2345	1564	2119
Pennsylvania	2896	1044	1551
Missouri	2370	1792	1803

Ganister brick made in	Specific gravity.		Porosity, per cent of volume.	Absorption, per cent of weight.
	True.	Apparent.		
Illinois	2.21	1.78	18.58	10.39
Pennsylvania	2.05	1.62	21.72	12.94
Missouri	2.16	1.74	19.31	11.29

Quartzite Bricks. — These are made from ground quartzite bonded with considerable fire clay.

Two types of American quartzite bricks showed the following analyses and results under tests of physical efficiency.

Constituents.	*H*	*P*	Constituents.	*H*	*P*
SiO_2	71.64	74.84	CaO	0.31	0.44
Fe_2O_3	1.93	2.07	MgO	0.45	0.60
FeO	0.40	0.24	K_2O	0.36	...
Fe	1.67	1.59	Na_2O	0.19	...
Al_2O_3	25.02	22.21	.....	...	...

Type.	Crushing strength, lbs. per sq. in.			Specific gravity.	
	Side.	Edge.	End.	True.	Apparent.
H	2139	528	297	2.35	1.95
P	no flat side	986	1588	2.40	1.96

Type.	Porosity, per cent volume.	Absorption, per cent weight.	Expansion, in. per lin. ft.
H	12.37	8.24	.080
P	18.38	10.27	.040

On account of the high percentage of clay these bricks show little expansion. Their strength is considerably less than the true silica but they are denser and heavier.

The Preparation of the Silica Brick. — The sandstone or quartzite which forms the essential constituent of all silica bricks is found in sedimentary formation. It is generally broken by drilling and blasting in quarries, and is seldom mined at depth. Both in Pennsylvania and in Wisconsin much of the rock is found in the form of boulders on the sides of the bluffs. These are broken by laying a stick of dynamite on the outside, covering with clay and exploding the dynamite. The millstone grit of the true ganister in Yorkshire underlies the Carboniferous and is an exception to the rule that the rock is found on or near the surface. The quarry rocks, boulders or broken ledges are examined carefully, and inferior, ferruginous, calcareous, or argillaceous rock is rejected. The quartz must be carefully crushed and ground and intimately mixed to insure the production of a strong firm brick. The silica rock is crushed first either by a gyratory or jaw crusher, and then ground in pan grinders or between rolls to the desired fineness, namely, that which will pass a mesh of 16 to the linear inch. The more friable sandstone and gravel, which are seldom satisfactory for fire bricks, may be ground direct in the Chilean mill or rolls. The hard quartz rapidly wears the cheeks of the jaw crushers and the steel of the gyratories.

Very few of the pure quartz minerals are suitable for refractory work, generally on account of physical rather than chemical deficiencies. Thus in the United States the silica brickmakers are restricted to the use of material from certain parts of Pennsylvania, Missouri and Wisconsin. In the British Isles, Dunkirk in Scotland, Neath in Wales and a part of Yorkshire furnish material. In Germany the silica is drawn from the northeast slope of the Siebengebirge and in the Rhine district between the Sieg, Lahn and Rhine.

A good quartz contains on an average about 97.5 SiO_2, 1.5 Al_2O_3, 0.5 Fe_2O_3, and smelts at cone 35 to 36 (1830 to 1850° C.). It is necessary to have some Al_2O_3 and Fe_2O_3 in the raw material since these form the particles of slag in combination with the silica, and these particles distributed throughout the whole mass make it porous and give it the property of a clinker. Nevertheless, the content of Al_2O_3 and Fe_2O_3 should not be greater than 2 per cent, and is generally 1.5 per cent. By regulating the quantity and character of the bases in the raw material, and noting the capacity of these bases for slagging and making infusible slags when they do combine with silica, an approximate idea of the possibilities of the material may be obtained.

Thin sections and fire tests avail little if these requirements are not filled. One condition seems to be necessary above all, that the raw material be rock, since sand and gravel give less satisfactory results. Further, no highly refractory brick will result unless the most intimate mixture of silica and bond be effected. The rock should possess a vitrified rather than a granular structure, and the ground material under the microscope should appear splintery, the particles of heterogeneous form, shape and size, and the whole semitranslucent. Alkalis may be present only in small quantities, not to exceed 0.2 per cent. Lime may be present in larger proportions, but all fluxes should not exceed 3 per cent. Alumina is not harmful when present in quantities up to 2 per cent, provided it is in the form of kaolin or silicate of alumina, which, while relatively infusible, sinters with the lime and some of the excess silica of the rock, and holds the brick firmly together after burning and produces a resonant hard clinker. While alkalis are harmful constituents, alkaline earths may be present in but small quantities. The law of the fusion and formation temperature of slags applies essentially in brickmaking. The greater the number of bases present, the lower the formation and fusion point of the slag or sinter, the weaker, therefore, at higher temperatures is the brick. Furthermore, the presence of alkalis and alkaline earths presupposes the existence, in the quartzite, of the original minerals which composed the igneous rocks whose decomposition produced the sedimentary quartzites. Among such minerals are the feldspars, mica and epidotes, all of which are themselves relatively fusible.

The Manufacture of Lime-Ganister, or Dinas, Brick. — This may be divided into four processes:

a. Selecting (and, if necessary, washing) the rock.
b. Selecting and burning the limestone.
c. Grinding and mixing the silica and lime, and pressing the brick. At certain plants some sand (not above 5 per cent) is added to the mixture in the pans.
d. Drying and burning the brick.

The washing is done in a revolving trommel. A stationary grizzly above this is inclined at such an angle that the rock will move. The upper end of the grizzly and trommel are sprayed, the water and mud running into a tank below the foundations.

After selection of the rock, care must be given to the degree of grinding and the intimate mixture of silica and lime in order that a good firm clinkered brick will be produced.

The Making of the Lime. — A pure, soft, white lime is generally used. This is obtained from burning limestone which has a high percentage of calcium carbonate and contains little magnesia. The limestone is burned at a temperature of 1000° C., in order to drive out all the carbon dioxide, which leaves the stone at 800° C. After burning the lime is slaked. Too high a temperature renders the slaking slow and difficult, especially in cases where the limestone contains silica and alumina. If magnesium carbonate be present in quantity above 9 per cent, it will make the lime worthless. The lime should be burned fresh. If raw stone is stored it takes up carbon dioxide and water. Sixty per cent of water by weight is added to the burned lime to slake it. This slaked lime may be kept some time in wet sacks without suffering chemical change. An illustration of a lime-burning kiln is shown in Fig. 7, which represents the kiln at the Mt. Union (Pa.) silica brick works.

The quartzite is stored in the open yard, since it can but improve by weathering. The lumps are broken into pieces which will feed into the jaw breaker or gyratory. If dirty they are first washed in the trommel. From the crusher the broken material is carried generally by an elevator to the mixing floor or to the pan grinder.

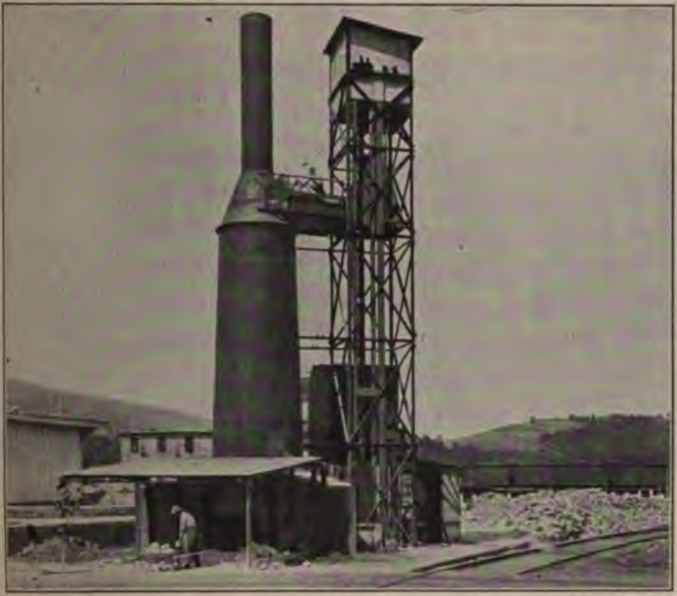

FIG. 7. — Lime-burning Kiln at Mt. Union (Pa.).

The lime is mixed on the same floor with the proper quantity of water (this may be done in barrels or in a mixing trough) and separated from the impurities, which settle to the bottom. The lime milk may then be strained through a fine mesh. The right proportion of lime to silica is of first importance in effecting strength of brick. The right mixture will produce a hard, ringing, clinkered brick, when otherwise a dull, weak product might result. The quartzite is now charged evenly on the pan of the grinding machine, and, after several revolutions, the approved quantity of milk of lime is added. An approved mixture in one factory is 75 parts of quartzite, 20 per cent of grog (old shapes), 1½ per cent lime and 5 per cent sand.

Another method is that of mixing the quartzite and milk of lime in a mixing trough on an upper floor and charging this mixture on to the wet pan grinders through a chute. Such is the procedure in the factory shown in Fig. 8, where the wet pan grinder is shown.

After the mixture is sufficiently well ground the mass is swept off the table by a scraper which may be attached to the revolving shaft, or it may be lifted out with a shovel.

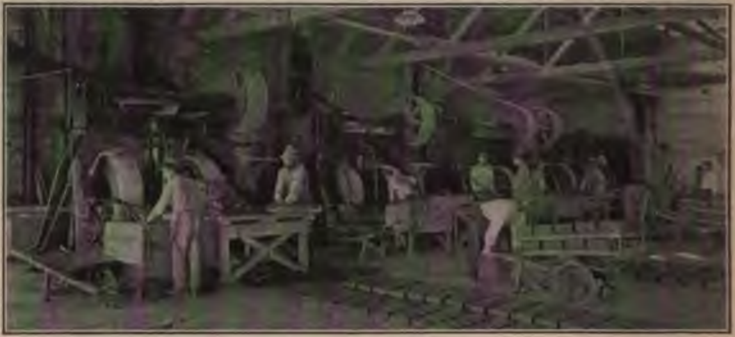

Fig. 8. — Wet Pan Grinder used in the Preparation of the Mass for Silica, Fire Clay and Magnesia Bricks.

The crusher and grinders wear very quickly and particles of iron are constantly found in the mass. Some of this oxidizes later and forms the red spots noticeable in ganister brick. In some factories all the quartz is not ground fine, but an effort is made to obtain a mixture of coarse and fine material of the following proportions: ⅓ powder, ⅓ grain of 1–3 mm. (about $\frac{1}{10}$ inch) and ⅓ grain, 3 to 7 mm. (average about ⅕ inch). The quantity of lime (CaO) should be as small as possible. This lime serves not only to make the mass mouldable but also forms the surface slag, lime silicate, which bonds the mass together and makes it a clinkered brick. This slag does not penetrate into the middle of the brick. Other bonds, suggested and used, include chloride of lime, magnesium chloride, alum, water glass, sugar, syrup, molasses, tar, rye, meal, etc. Further sulphuric acid has been added to sulphatize the lime. A German patent (D R P 69,318) proposes to use gypsum with the addition of aluminum sulphate or magnesium sulphate as bond. For instance, two per cent of gypsum and one of aluminum sulphate may be used as a bond, with 0.85 lime and 0.15 alumina as fluxing agents. To increase the plasticity of the mass an addition of several per cent of fire clay is made; but the total CaO and Al_2O_3 should not be more than four per cent of the mass.

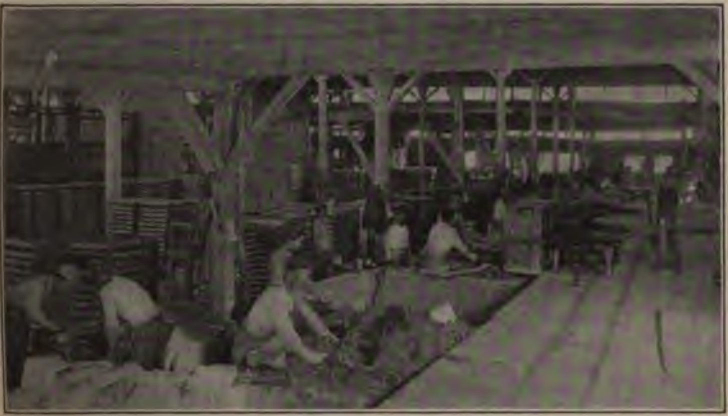

FIG. 9. — Moulding Floor. (The man on the upper floor has brought the thoroughly-tempered mass in the dump car from the wet pans: the workmen in the foreground are moulding the brick.)

Moulding. — The moulding of the bricks may be done in open wooden or iron moulds, with a second finishing-shaping in a hand press; or the bricks may be formed by a hydraulic press sometimes equipped with a revolving table. Shaping by hand in open moulds is preferable. An iron plate is pushed under the mould, which holds six bricks. The batch is worked and pressed in the mould, the bricks are shaped and levelled, and then the mould is lifted out of the batch and away from the plate. The whole plate with the shapes is then pushed on to a buggy rack. Fig. 9 shows the method of transferring the mass from the wet pans to the moulding floor and the process of hand moulding. In

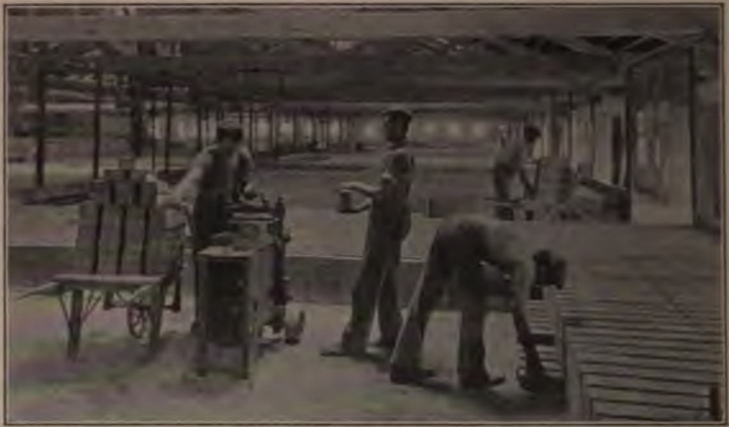

Fig. 10. — Repressing Shapes.

the background are seen the tunnels in which the bricks are dried. Fig. 10 shows the method of repressing dried bricks, a process much less often used for silica than for fire bricks.

Drying. — The dinas and ganister bricks must be dried quickly and thoroughly before being burned. The bricks should

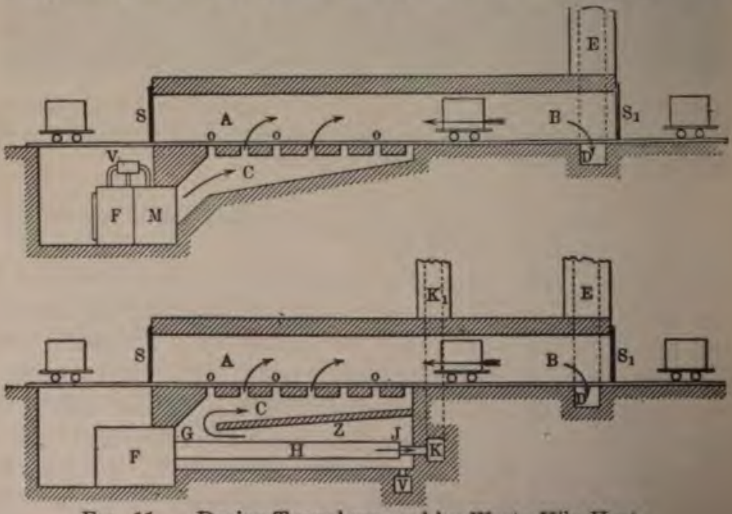

Fig. 11. — Drying Tunnel warmed by Waste Kiln Heat.

be first stacked, preferably on a hot floor, and await for a week or more their transfer to the kilns. It has recently been suggested that the bricks be dried in cylinders under steam pressure of several atmospheres, just as is done in the manufacture of sand-lime brick. The usual method, however, is to dry them on buggy racks in drying tunnels heated by steam or hot air. (See Fig. 11.) This hot air is generally obtained from a brick kiln which is in the process of cooling. If steam is used it is applied in coils or pipes laid under the racks or under and about the tunnel and is obtained from boilers which are heated by the waste heat from burning brick in kilns or chambers. The process of drying in the tunnels takes from 10 to 20 hours.

Burning. — Silica bricks are burned for a period of from 7 to 10 days at a temperature which rises as high as 1600° C. An effort should be made to obtain a temperature in the burning kiln higher than that at which the bricks will be employed in the industries afterward. The bricks should be set as free as possible in the kiln, and should not be overweighted, and it is highly important that after the burning they should be cooled slowly. A system of firing should be used which prevents the possibility of a draft of cold air suddenly chilling the brick during the process of burning. Round kilns of the downdraft type are almost universally used, with either natural draft fire boxes or the Parsons' system of forcing draft by means of steam jets. This type of kiln is shown plainly in Figs. 12 and 13. In Germany a system of kilns is connected and called a Kam-

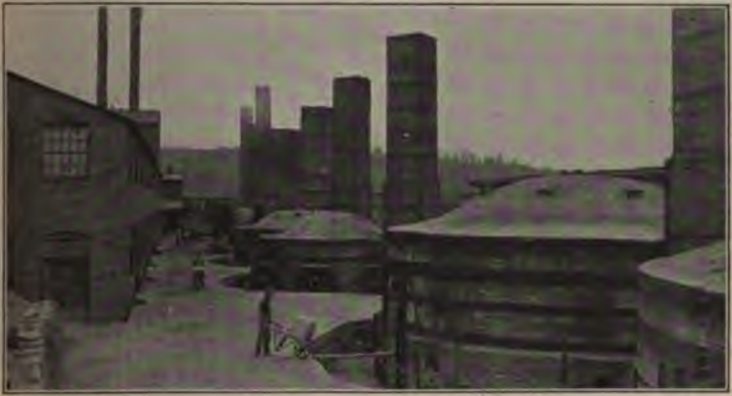

FIG. 12. — Round Downdraft Kilns.

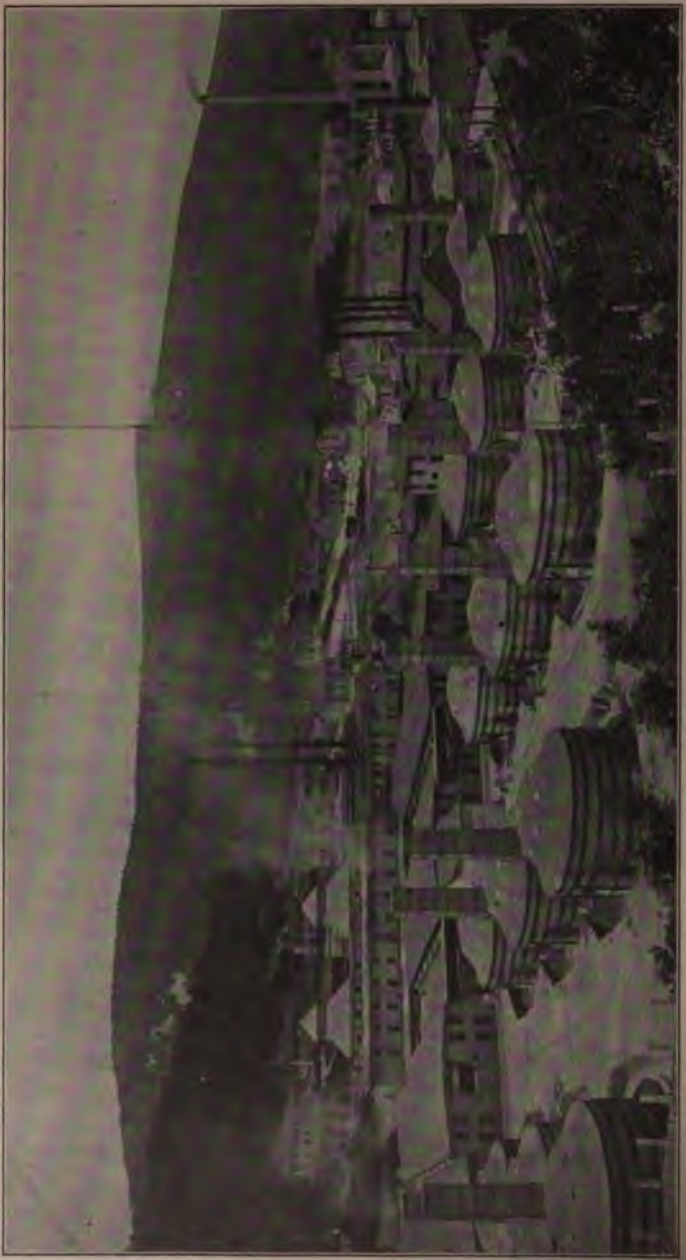

FIG. 13.—Downdraft Kilns at Mt. Union (Pa.) where the Excess Heat is used to produce Steam Power from Boilers.

merofen. These have the advantage of conserving the waste heat since the hot air from one furnace is used in the neighboring furnaces, but the particular chamber in which the bricks have just been burned must be shut off until its temperature has fallen to about 700 or 800° C.

Burning silica bricks is a long and tedious business; the only way to hasten it would seem to lie in expediting the cooling, which might be done without danger, by blowing in hot air. The dinas and ganister bricks are liable to crack if cooled too quickly or unevenly. The kilns are of various sizes. The large type of round American kiln holds 100,000 brick. A kiln which holds 30,000 brick is 12 to 15 feet in diameter and 13 feet high at the spring of the dome. This kiln would have from six to eight fire boxes. Bricks for special purposes may be burned several times; the first time at Seger cone 16, the second time at cone 18 and the third time at cone 20. Especial pains must be taken in moulding, drying and burning difficult shapes such as are shown in Fig. 14. These are moulded by hand in wooden forms and dried on a floor heated by underlying steam coils or by overhead hot-air pipes, which are clearly shown in Figs. 14 and 15. These hot floors replace the drying tunnels. Still greater care is exercised in setting the "difficult" shapes in the kiln. They are generally laid high in the kiln on top of normal shapes so that they have but little weight to carry.

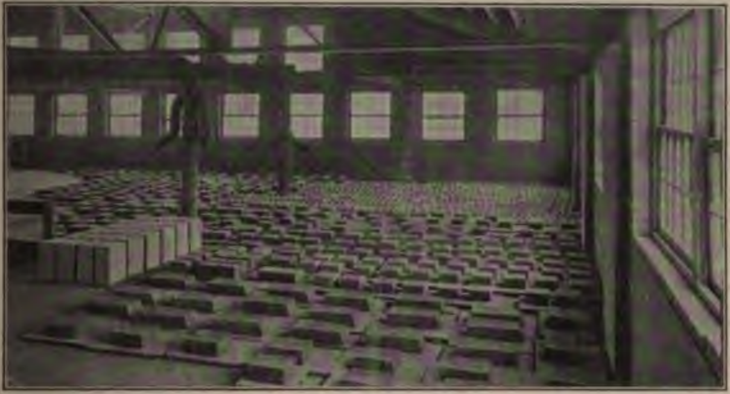

FIG. 14. — Drying Floor.

The ordinary standard bricks and forms are placed on edge, two rows always being set in the same order, and the next two rows at right angles to the next inferior rows. At certain regular intervals a row of burned bats is set to support the higher rows. The whole kiln should not be filled with green unburned brick, since this would cause the lower rows to be too heavily weighted. The greatest weight that should be allowed to rest on any row of bricks should not exceed 3 pounds to the square inch.

FIG. 15. — Wheeling Shapes to Kiln from Drying Floor.

The operation of burning may be divided into three periods of (1) dehydration, (2) oxidation and (3) vitrification. The temperature rises in the first to 300° C., in the second to 900° and in the third to 1500 or 1700° C. The draft rises during the first period to 4 mm., and is gradually reduced during the last to about 2 mm. The whole operation is controlled by water testing rods, pressure gages and pyrometric cones. Further information on the process of burning is given in the chapter on the manufacture of fire-clay brick.

Properties and Application. — Owing to their porous character silica bricks are light, brittle and not easily worked. They are only fair conductors of heat, break if heated with insufficient regularity, and under rapid change in temperature they become friable and crack. They are easily attacked by basic slags, metal oxides and flue dust. They are the best of all fire bricks to employ where constant high temperatures are used and where acid slags are produced. They are superior to fire-clay bricks in that they expand regularly at high temperatures. This is of value wherever mortar is used and especially in crowns and arches, for fire-clay bricks expand scarcely at all, and all mortars shrink. The commonly accepted axiom that a fire-clay brick shrinks on using in industrial furnaces must be modified. As a rule it expands somewhat when the furnace is in heat, but contracts considerably from its original dimensions when the furnace is cooled.

On account of the high modulus of expansion of the silica brick they must not be laid too closely. Tie bars must be slackened as the bricks expand, and to minimize danger of cracking the firebrick walls and roof must be heated gradually, evenly and slowly. The best mortar to use is ground silica brick in a little fire clay, or quartz sand mixed with lime.

The Silica Brick with Clay Bond, Called the English Ganister. — The ganister, or millstone grit, is a thick clay-bearing Carbonaceous sandstone of gray or reddish-brown color, which occurs in the districts of Sheffield, of Dowlais (Wales) and of Gartcosh (Scotland), and underlies the Carboniferous measures. Analyses of Sheffield and Dowlais stone resulted as follows:

	Sheffield.		Dowlais.
	Per cent.	Per cent.	Per cent.
SiO_2	94.40	95.55	93.05
Al_2O_3	4.21	4.85	4.23
Fe_2O_3	0.70	0.85	0.80
CaO	Trace	0.60	0.26
MgO	Trace	0.11	Trace
Alkali	.....	0.94	.....
Loss on ignition	0.69	.....	1.00
	100.00	102.90	99.79

In Wales 8 per cent of fire clay is added to increase the plasticity; less is added to Sheffield material.

The composition of English ganister bricks is as follows:

	Gartcosh, No. 1.	Gartcosh. No. 2.	Sheffield.
	Per cent.	Per cent.	Per cent.
SiO_2	87.06	74.10	88.56
Al_2O_3	11.24	22.32	10.16
Fe_2O_3	0.69	2.28	0.97
CaO	Trace	0.48	0.04
MgO	Trace	0.34	.....
Potash	0.61	.....	.....
Soda	0.33	0.38	.....
	99.93	100.10	99.73

German ganister, also called German dinas brick, analyzed as follows:

	Rhine dinas for cupolas.	Puddle furnace special brick.	
	Per cent.	Per cent.	Per cent.
SiO_2	92.80	90.84	92.85
Al_2O_3 Fe_2O_3 Fluxes	5.94	9.16	4.95 0.87 1.83
Loss on ignition	.....	.....	.....
	100.00	100.00	100.00

German natural ganister, blocks hewn from Crummerdorf quartz shale, analyzed thus:

Per cent.
SiO_2 = 88.14
Al_2O_3 = 6.11
Fe_2O_3 = 0.45
Alkalis = 5.30
100.00

This rock is grayish white and has a specific gravity of 2.1 to 2.35. This material seems especially suited for the linings of lime and cement furnaces. Kerl reports * that in testing this material for refractories, cones were made of marble and of cement and their action in fusing on test blocks of fire-clay brick, on true dinas brick and on quartz shale determined. At 1450° C. the quartz shale was least attacked. The fire clay was eaten out into a hollow under the cone and this was filled with a glassy slag, while a similar slag penetrated the heart of the dinas. Without combining chemically with the mass it penetrated the pores of the silica brick, while the homogeneous natural quartz shale resisted any infusion of the slag. Further tests proved that sandstone and lime showed less affinity to form slag than the fire clay and lime.

Between the clay ganister or dinas bricks and the true fire clay lies a class called the quartzite brick, made by bonding quartzite material, generally sand, with considerable clay. The

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* *Handbuch der Gesammten Thonwaarenindustrie* (1907), p. 904.

bricks were made with the idea of combining the virtues of the silica brick; namely, extreme refractoriness at high temperatures, with the physical superiority in strength of the fire clay; they should not expand as much as the silica brick. Generally, the mixture consists of two parts of sand, gravel or crushed quartzite to one of fire clay. Fine powdered quartz is not suitable. Within reasonable limits the silica should be rough and coarse. Kerl states that * the addition of quartz dust to clay, both melting at Seger cone 35, gave a mixture melting at cone 33. Sometimes fine coal dust is added to the mixture of clay and sand, in order that the volume of the brick may not change after several heats. For instance, in Germany bricks are made from a batch containing:

1 part clay from Passau, 2 parts sand and some fine coal dust.

Another refractory mixture is composed of:

31 parts unburned Belgian clay, 52 parts burned Belgian clay, in grains of 2 to 3 mm., 17 parts quartz.

The Austrian State Railways use in their converters:

2 to 5 parts unburned clay, 6 parts burned clay and 1 part quartz.

These bricks are not so strong as the fire clay, but are more easily worked, and are more plastic than the dinas and ganister masses. The clay is ground fine; to this the quartz is added. Then the mass is worked with water, kneaded and formed into bricks, which are dried and burned. These bricks are not long lived since they are constantly changing in chemical and physical constitution owing to slag action, which tends to disrupt them.

An English brick containing 66.5 SiO_2, 29.74 Al_2O_3 and 2.65 Fe_2O_3 melted at cone 31 (1750°), and showed a linear expansion of 1.2 per cent after the first heat, 2.2 per cent after the second, 2.77 after the third, 3.14 after the fourth and 3.59 after the fifth.

The quartz-clay bricks are used in puddling, malleable, cupola and crucible furnaces, in coke furnaces (for the base flues), for converter linings and in glass furnaces.

American quartzite bricks analyzed as follows: †

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* *Handbuch der Gesammten Thonwaarenindustrie* (1907), p. 905.

† Private communication.

Sample.	SiO_2.	Fe_2O_3.	FeO.	Fe.	Al_2O_3.	CaO.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
H......	71.64	1.93	.40	1.67	25.02	0.31
BB.....	74.84	2.07	.24	1.59	22.22	0.44
....	.....	MgO	K_2O	.....	Na_2O	.....
H......	.....	.45	.36	.....	.19	.....
BB.....	.....	.60	.....	.....	.....	.....

Sample.	Crushing strength, pounds per square inch.			Specific gravity.		Porosity, per cent volume.
	Side.	Edge.	End.	True.	Apparent.	
H......	2139	528	297	2.35	1.95	12.37
BB.....	....	986	1588	2.40	1.96	18.38

Sample.	Absorption, per cent weight.	Expansion, inches per linear foot.
H..........	8.24	.080
BB........	10.27	.040

The dinas and ganister bricks proper are now extensively used in coal-gas retorts, in the lining of by-product coke ovens, such as the Semet-Solvay, Koppers and Otto Hoffman, for the crowns and domes of beehive coke ovens, for the hearth and side walls of glass furnaces, in open-hearth furnaces, for copper refining, in converters, both in the form of mass and of large forms, in regenerative checkers and in crucible steel melting furnaces, where silica has replaced fire brick almost entirely. Difficult shapes are less often made of silica than of fire clay. It must always be borne in mind that the smaller the brick used the more elastic and durable will be the structure, and that the homogeneity and even vitrification-slagging is most easily obtained in small sizes. The use of small sizes is also encouraged by their regular expansion.

EXPANSION IN DINAS BRICKS*

The expansion of dinas or silica bricks is said to be due to the conversion of the quartz into tridymite. The microscopic examination of a piece of dinas brick, which has been exposed for a long time to the heat of a furnace, shows numerous crystals of tridymite in the ground mass, consisting, according to the amount of iron present, of a brown, red or yellow glass surrounding the larger quartz grains.

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* *Engineering and Mining Journal*, Dec. 16, 1911.

Apparently the quartz does not pass directly into tridymite, but is first converted into a vitreous, amorphous or molten condition of lower density than tridymite. In sections of dinas bricks, which have been completely melted down, owing either to prolonged heating or to large amounts of fluxing materials, traces of tridymite are wanting, and in their place strongly reflecting isometric crystals are found; these are probably crystobalite, which is stable at a higher temperature than tridymite. As a rule the quartz grains of dinas bricks are penetrated by fine cracks from which the vitrification starts, and the larger the number of cracks, the larger the number of small grains into which the crystals split and the more rapid the increase in volume on heating.

Analyses of Wisconsin Ganister Rock *

Name.	Loss on ignition.	SiO_2.	Fe.	Fe_2O_3.	Al_2O_3.	CaO.	MgO.
1. Devils Lake	0.28	97.99	0.70	1.69	0.99	0.01	0.03
2. Ledge, Devils Lake	0.54	97.95	0.70	1.49	0.79	0.01	0.01
3. Ledge, Devils Lake	0.40	98.84	0.33	0.74	0.41	....	0.02
4. Ledge, Devils Lake	0.59	97.98	0.90	1.40	0.50	0.01	0.02
5. Ledge, Devils Lake	0.70	98.12	0.36	1.15	0.79	0.02	0.01
6. Ledge, Devils Lake	0.45	98.11	0.41	1.41	1.00	0.02	0.01
7. Inferior ledge, Devils Lake	0.56	96.62	0.79	2.79	2.00	....	0.03
8. La Rue	0.46	98.22	0.23	1.31	1.08	....	0.01
9. Road material, Wisconsin Granite Co.	0.79	94.82	1.07	4.33	3.26	0.01	0.05
10. Baraboo	0.62	97.93	0.17	1.44	1.27	....	0.01
11. Baraboo	0.60	98.59	0.23	0.76	0.53	0.03	0.02
12. Baraboo	0.44	98.81	0.08	0.75	0.67	....	....
13. Baraboo	0.33	99.04	0.28	0.65	0.35	....	....
14. Best hard rock for road making	0.51	97.17	0.97	2.32	1.35	....	....
15. Narrows Creek (Baraboo)	0.52	98.51	0.16	0.97	0.81	....	....

* Communicated by Dr. Victor Lenher.

The percentage composition of material suitable for making dinas bricks should be about 97½ per cent silica, 1½ per cent alumina, 1½ per cent ferric oxide and small amounts of alkalis and magnesia. The lime added as a binding material should not exceed 2 per cent of the mixture. Microscopic examination of burned dinas brick shows that there is practically no diffusion among the raw materials unless the brick has been actually melted. In an ordinary dinas brick, from one-third to one-half the whole amount of quartz present has been converted into tridymite or crystobalite and a change of the remainder takes place more or less slowly in the furnace, but probably other factors such as porosity, the formation of fusible solutions, the change of the glass into tridymite, etc., tend to counteract the increase in volume.

Kieselguhr. — The most porous silicious refractory material used is Kieselguhr or infusorial earth which is really the silicified remains of small animal organisms.

Samples from Oberhohe in Germany analyzed:

	1.	2.
SiO_2	87.859	74.48
Al_2O_3	0.132	.....
Fe_2O_3	0.731	0.39
$CaCo_3$	0.750	0.34
Organic matter	2.279	.....
Water	8.431	24.43

As a refractory material it has not proved as satisfactory as the quartzites, such as dinas.

Dr. Jos. W. Richards* describes a refractory material called "Moler" which is a diatomaceous clay found in Jutland. When moulded and burned alone without admixture of any kind, the resulting brick is light, firm and so tough that a nail may be driven through without cracking it.

The specific gravity of the burned bricks ranged from 0.87 to 1.13, the crushing strength was 86 to 230 kg. per square centimeter and they had the capacity of absorbing 50 per cent of their weight of water. They are said to make splendid heat insulators but may not be used where exposed to moisture in the air.

Their high porosity makes their heat conductivity unusually low. They have been tested in furnaces heated to 1100° C. and found satisfactory.

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* *Electrochemical and Metallurgical Industry,* Vol. VII, p. 474.

Home-made Silica Brick. These have been made at times in remote districts particularly in constructing copper-refining furnaces. A description of the method used at a remote Mexican smeltery is given in the section "Copper-Refining Furnaces," in Chapter VII, page 161.

CHAPTER IV

THE PREPARATION OF THE REFRACTORY CLAYS

Refractory Materials Containing Alumina as an Essential Constituent. — Under this heading are classed those clays which have a fairly high fusion point, such as certain kinds of mud and adobe clay, fire and potter's clay, flint clay, kaolins and shales.

The term clay embraces all the alumina silicates which may absorb water and derive therefrom sufficient plasticity to make them mouldable. This moisture they lose temporarily by drying and permanently when burned at high temperatures. Chemically the clay is a double silicate of alumina, consisting of hydrous silicate of alumina, with silicates of the alkalis, alkaline earths and iron. Water may be present, both chemically combined and free. Neither the hydrous silicate nor the double silicate of alumina is found pure in nature except in the form of minute crystals of kaolin.

Clay occurs in nature either as such, or as a constituent or bonding body of rock masses such as conglomerates and sandstones, as "walls," between veins and country rock, and is found in every formation of every geological period.

It is not an original formation but the result of weathering, and, accordingly, is more widely distributed in the younger than in the older formations. It is almost entirely by chemical dissolution and mechanical destruction of the feldspar-bearing rocks that we obtain our deposits of clay. The slimy sediments form definite layers of compressed mineral, and at the same time an autogenous mixing of the original sediments results in a complete recrystallization into our present clay, clay slate and phyllite or micaceous clay slate. Owing to admixture of sand the pure clay will become mud or loam; it is to an addition of lime or dolomite to clay that we owe our marls, calcareous clay schists and calcareous phyllites. Of all these classes of clay only a small proportion are suited for fire clays. These result almost entirely from the decomposition of the eruptive rocks high in feldspars, which yield kaolinite under the influence of leaching and weathering. We might then classify the clays into two types, the kaolin clays suitable for refractory work and the common clays.

In the course of deposition, sand, mineral particles and clay substances are separated according to the specific gravity. A stream will deposit coarse sand and carry heavy clay mass in suspension to deposit later in a lake. Accordingly, we find clays either bedded, resulting from intermittent deposition, or homogeneously massed, the result of continuous deposition through a long period of time. To this latter class belong the plastic clays. Should the pressure on the beds have been considerable, it often happens that the plastic clays become hard and dense.

The principal constituents of clay are first, kaolinite, $Al_2Si_2O_7$ $2\ H_2O$, with 39.7 Al_2O_3, 46.4 SiO_2, 13.9 H_2O; also, sand of primary or secondary origin, which reduces the refractoriness of the clay, and "schluff," a fine product formed by the weathering of the mother rock and consisting of various minerals which resist kaolinization. In considerable quantities it renders clays fusible and unsuitable for refractory work.

Clays are sometimes classed as fat, lean, plastic, slate, bituminous, marl and mud (loam).

The more common impurities in clay are derived:

1. From original, unchanged, rock particles, mechanically mixed, such as quartz, feldspar, mica.
2. From contemporaneously formed products, such as lime and magnesia carbonate, hydroxide of iron, etc.
3. From later admixture from foreign rocks, such as sand, bitumen, etc.

Clays may carry pebbles, lime shells and caprolites, feldspar, mica, sand, organic remains, carbon, resin and glass particles of volcanic origin, also pyrite, generally in the form of marcasite, iron phosphates, alkali salts, titanium, gold, chromium, fluorine and boric acid.

Color of Clay. — Seger classifies the clays according to color as follows:

a. Clays containing small quantities of iron which burn white. The iron content may amount to several per cent.

b. Clays containing a moderate quantity of iron. These burn pale yellow to brown, such as plastic clays with 20–30 per cent

Al_2O_3 and 1–5 per cent FeO and Fe_2O_3 which are suitable for fire ware.

c. Clays with considerable iron, burning red, violet or blue black.

d. Clays high in iron and lime, low in alumina; they burn first red, and, at higher temperatures, white; in melting assume green, dark green and black colors.

Mineralogically, Ries* suggests that clay consists of: (1) fragments of numerous minerals, oxides, carbonates, silicates, etc., some fresh and some in a process of decomposition or decay, and (2) of colloidal material of organic or mineral origin. The mineral parent is in most cases a feldspathic rock, in other cases such rocks as gabbro and serpentine, which weather into very plastic clays, though low in alumina.

The process of disintegration and change of rock into clay is accomplished by varying kinds of weather, the alternate heat and cold thus opening them and allowing the silicates to be attacked by the surface water. Cameron and Bell † show the action of water by the following formula:

$$KAlSi_3O_8 + H_2O = KOH + HAlSi_3O_8.$$

The $HAlSi_3O_8$ by losing some of its silica may change under the action of weather and water into kaolinite ($Al_2O_3SiO_2$), and the alteration of the feldspar is called kaolinization. This process may also be effected by the action of mineralizing vapors. This is discussed by Ries.‡ Ries classifies the clays into residual (formed by decomposition of rocks in situ), colluvial (formed by wash from the residual) and transported clays. Where the clay is found overlying the rock from which it was formed, representing the residue of rock decay, it is called a residual clay. When derived from a rock composed entirely of feldspar with little or no iron oxide, it is usually white and is, therefore, termed a kaolin, which may or may not have contained a high percentage of the mineral kaolinite. It is important to remember that the word kaolin is used to denote the clay, while kaolinite signifies the mineral.

An analysis of the natural kaolin from King-te-ching used in the manufacture of the finest porcelain resulted as follows:

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* *Md. Geol. Sur.*, Vol. IV, 251, 1902.

† Bur. of Soils, Bull. No. 30, p. 16, 1905.

‡ "Clays," p. 5.

	Per cent
Silica (SiO_2)	73.55
Alumina (Al_2O_3)	21.09
Ferric oxide (Fe_2O_3)	trace
Lime (CaO)	2.55
Magnesia (MgO)	.15
Potash (K_2O)	trace
Soda (Na_2O)	trace
Water (H_2O)	2.62
	99.96*

A washed kaolin from Hoc Ressin, Delaware, shows a very striking difference in composition. An analysis of this gave 48.7 per cent silica, 37 per cent alumina, 0.79 ferric oxide and 12.83 per cent water.

The extent of the residual clay and the manner of its occurrence in a bed or a ledge, its color and depth, depend on the shape and extent of the original rock deposit, its chemical composition and the climatic conditions and location under which the parent rock was changed.

On the distribution of residual clays Ries says that they are usually of a ferruginous character in many parts of the United States, and reach their maximum of development in that portion lying east of the Mississippi and south of the southern margin of the ice sheet of the glacial period. North of the terminal moraine they are found only in protected areas which escaped the glacial action. One of the better clays of Wisconsin is found in the driftless area. Another is found underlying the Potsdam sandstone, proving its great geological age. An analysis of such residual clays will show from 39 to 71 silica SiO_2, from 12 to 29 Al_2O_3, from 5 to 18 iron oxides, 1 or 2 per cent of soda and potash and 4 to 14 per cent water.

Residual clays can scarcely remain on slopes, but are washed away by rain into streams to settle in lower and sometimes distant areas. In the process of washing and transporting and, when the velocity of the stream is checked, a deposit of clay is formed by one layer of sediment being laid down on top of another and, as there is considerable variation generally in the grain and quality of the layers, one layer will tend to separate along the line of contact with another. As fine material can only be deposited in quiet water, while coarse material deposits in disturbed water, we may and do have layers of these one on top of the other, showing how the life of the stream changed. Clays deposited in this manner are called sedimentary. They are unlike the rock on which they rest and are always stratified. In addition to the deposits made by streams we have the marine clays deposited on the ocean bottom at some distance from the shore, estuarian clays, such as those of the Hudson Valley and the Hackensack region of New Jersey, swamp and lakelike clays (which are used for common brick and earthenware), flood, plain and terrace clays (from which we get all kinds of material suitable for pottery, tile and brick), drift and æolian clays deposited by wind action.

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* G. P. Merrill, "Non-Metallic Minerals," p. 224, 1904.

Orton* has classified clays as follows:

High-grade clays (50 per cent or more kaolin) with silica.	Low-grade clays (10 to 70 per cent kaolin with variable per cent fluxing elements.
Kaolin	Argillaceous shale-paving block
China clay	Ferruginous shale-pressed brick
Porcelain clay	Silicious clays — sewer pipe and paving block
Fire clay (hard)	Tile clays
Fire clay (plastic)	Brick clays
Potters' clay	Calcareous shales — bricks

The Mineralogical Composition of Clays. — Besides kaolinite and its kindred hydrated silicates of alumina, such as halloysite, thorolite, allophane and pyrophyllite, the following minerals are present in various clays: quartz, feldspar, mica, oxidized iron ores as well as pyrite, calcite, gypsum, rutile, which are of widespread occurrence in clays; glauconite, a hydrosilicate of potash and iron; dolomite, magnesite, both highly refractory but when mixed with other minerals exerting a fluxing action even as lime and other earthy oxide; zinc blende and garnet; tourmaline, which occurs in kaolin; and, in some cases, rare elements such as cerium, yttrium and beryllium.

The actual chemical analysis gives less clue to the properties of the clays than the rational analysis which has for its object the determination of the different mineral compounds present, such as quartz, clay substance, feldspar. Naturally, clays which have a similar ultimate analysis may have an altogether different rational analysis. For the methods of making the ultimate analysis readers are referred to Ries.†

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* Ohio Geol. Survey, Vol. VII, p. 52.

† "Clays," pp. 64, 68.

In fire clays the alumina should be present in sufficient quantities to form a bisilicate with the silica present. Any silica above this is either in a free condition or in the form of alkali, or metal-oxide silicates. In both forms it reduces the refractoriness or infusibility of the clay by acting as a flux. The content of the alkalis must be very low, as a rule not greater than 2 per cent; the alkaline earths and metal oxides may be present in only small quantities. In fact, the percentage of bisilicate of alumina should be at least 90.

Bischof realised this when determining the refractory coefficient. He has been followed by Wheeler and others in working out formulæ which originally were based on the following:

Let Q be the refractory coefficient, the oxygen content of the alumina, a, of the silica, b, and of the fluxes, c.*

Then $$Q = \frac{a^2}{bc}.$$

Now Q in refractory material may vary between 2 and 14. A refractory coefficient from 2 to 4 means that the clay will make a third-class fire brick; a coefficient of 4 to 6, a second-class fire brick; of 6 to 14, a first-class fire brick.

For instance:

CLASS 1. — First-class fire brick. Clay from Altwasser:

	Per cent	
Al_2O_3	36.30	Oxygen content 16.92

SiO_2 (chemically combined 38.94, sand 4.90) 43.84. Oxygen content 23.36.

MgO	0.19	Oxygen content is 0.293 × 3 = 0.879.*
CaO	0.19	
FeO	0.46	
K_2O	0.42	
Loss	17.78	

Refractory coefficient $\frac{a^2}{bc} = 13.95$.

CLASS 2. — Washed kaolin from Zettlitz, Bohemia.

	Per cent	
Al_2O_3	38.54	Oxygen content 17.96

SiO_2 (chemically combined 40.53, sand 5.15) 45.68. Oxygen content 24.363.

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* The oxygen content of the bases (protoxides) is multiplied by 3. See page 273.

MgO	0.38	Oxygen content is 0.467 × 3 = 0.401.
CaO	0.08	
FeO	0.90	
Loss on ignition	13.00	
K_2O	0.66	

Refractory coefficient 9.49.

EXAMPLE 3. — Belgian plastic clay.

Per cent

Al_2O_3.......... 34.78 Oxygen 16.208.

SiO_2 (chemically combined 39.69, sand 9.95) 49.64. Oxygen content 26.457.

MgO	0.41	Oxygen content is 0.778 × 3 = 2.364.
CaO	0.68	
FeO	1.80	
K_2O	0.41	
Loss on ignition	12	

Refractory coefficient 4.21.

EXAMPLE 4. — Sedimentary kaolin clay from Grünstadt.

Per cent

Al_2O_3.......... 35.05 Oxygen 16.334.

SiO_2 (chemically combined 39.32, sand 8.01) 47.33. Oxygen 25.225.

MgO	1.11	Oxygen content is 1.490 × 3 = 4.470.
CaO	0.16	
FeO	2.30	
K_2O	3.18	
Loss on ignition	10.51	

Refractory coefficient 2.37.

EXAMPLE 5. — Cassel clay — under the brown coal beds.

Per cent

Al_2O_3.......... 27.97 Oxygen 13.035.

SiO_2 (chemically combined 33.59, sand 24.40) 57.90. Oxygen 30.908.

MgO	0.54	Oxygen content is 0.983 × 3 = 2.995.
CaO	0.97	
FeO	2.01	
K_2O	0.53	

Refractory coefficient 1.86.

Even with this coefficient the clay is refractory. When mixed with certain proportions of more refractory material this could make a fair quality of fire brick.

The refractory coefficient $\frac{a^2}{bc}$ is derived as follows: The relation of alumina to silica, or $\frac{a}{b}$, divided by the relation of the fluxes to alumina, or $\frac{c}{a}$, is the refractory coefficient or $\frac{a^2}{bc}$. This method of determining the refractoriness is fairly accurate for technical purposes. It cannot be exact since it does not take into consideration physical qualities — density, porosity, size of grain, manner of burning and other factors, which influence the refractoriness and the degree of fusibility, such as number of bases present.

The texture is especially important. As a rule, the more coarsely grained material is the more refractory; if of uniform composition and grain, there should be no difference in the fusibility of a coarse and fine sample of the same material. If, however, the fine parts are highly aluminous and the coarse parts very silicious, when the clay is heated, active fluxing between the clay and silica is prevented and the clay fuses at a higher point than one might assume from the chemical analysis.*

Tensile Strength. — Fire clays vary in tensile strength, and often, though sufficiently refractory, must be strengthened by the addition of some plastic material, even at the cost of refractoriness.

Colors. — Fire clays are of all colors. Since ferrous and ferric oxide both are active coloring agents, a very low percentage of such impurity may discolor a clay which has a high refractory coefficient and is a fairly pure aluminum silicate. As a rule, the better quality flint clays are white or gray, and china clay or kaolin is quite white.

Plasticity. — As a rule, the fire clays belong to the lean and flint class. The more plastic clays are seldom very refractory.

The origin of the quality of plasticity has never been fully determined. The various theories to explain this quality have been admirably summarized in Dr. Ries' book, "Clays, Occurrence, Properties and Uses." Bischof suggests that it is due to the presence of some particular hydrated silicate of alumina, while Seger, the originator of the pyrometric cones, thinks that the plasticity is determined by the effective molecular arrangement of the structure of the parent rock. Another theory that plasticity is due to a colloidal condition of the fine particles or some proportion of the particles which constitute the clay mass has been discussed along with the plate theory (that most plastic clays were composed of small transparent plates bunched together), the interlocking grain theory (the interlocking of the clay particles), the molecular attraction theory (due to molecular attraction between the clay particles themselves or between the clay grains and water surrounding them), the bacteria theory (the addition by bacteria of organic colloids to clay) and other theories. The plasticity of a clay may be increased mechanically by exposing it to changes of the weather or in some cases by grinding.

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* Ries, "Clays," pp. 178, 211.

The fire clays are divided into the two main classes: flint clay and plastic clay. The latter is added to the former to increase the deformability, generally at a cost of its refractoriness. The flint clays contain a large percentage of kaolin. They are mined generally in the Carboniferous formations, often under a layer of coal.

Weathering adds to the refractoriness of many fire clays. Those containing iron oxides and sulphides dissociate in the air, rain carries off the iron salts and the clay is improved in purity, plasticity and homogeneity. Carbonate of lime, in dissociating in the presence of the pyrite, is leached in the form of gypsum, and the various organic substances further the dissociation and help to form soluble salts. The Stourbridge and Garnkirk clay slates in England are piled for this reason in heaps 20 feet high, and exposed for years to the weather, thus becoming purer, more plastic and more refractory; that is, the percentage of alumina is increased, while the fusible alkali oxides and salts are removed.

Washing is even more effective. Water separates coarse grain from fine, the clay proper from salts, from sand and quartz, and carries off in solution alkali salts, thus freeing the material from the potash which is a most effective agent in promoting fusibility and in reducing the grade of refractoriness. Acids are a costly and scarcely effective means of dissolving out impurities. A combination of organic weathering and washing will do the work more cheaply and better than the use of strong acids.

In order to determine the capacity for bonding which a clay possesses, it is necessary to resolve how many parts of it are required to bond one part of grog or chamotte, crushed to pass a 10-mesh sieve, into a brick of good physical properties.

A very plastic fat clay burns to a close mass, but cracks and shrinks in drying and burning. It must be used then in combination with some lean clay or grog which is more refractory, but demands a bonding material to make it cohere.

The lean or flint clays are generally calcined in order to drive out moisture, carbon dioxide and to burn bituminous and carbonaceous matter. These clays are frequently found below the coal measures and carry a considerable percentage of carbon. Because they are thus calcined before being transported to the works, they are frequently called grog or chamotte and classed with the burned and previously discarded bricks and shapes in making mixtures on the selecting floor.

Fire clay forms the basis of by far the greater proportion of refractory ware. It is either used alone on account of its admirable qualities of burning to a firm clinker and resisting high temperatures and mechanical abrasion, or it is added to other refractory matter such as quartz, bauxite, magnesia, sesquioxide of chromium and plumbago to lend plasticity.

Fire clays are widely distributed throughout the world. In the United States, Kentucky, New Jersey, Pennsylvania, Ohio, Missouri and Colorado furnish the best deposits for the manufacture of fire brick, while pure kaolins are found in Illinois, North and South Carolina and Texas. In Germany the fire clays of Hesse are famous, such as those of Grossalmerode, Ebernhahn and Ramsbach. In Silesia the clays of Bunzhan are noted; in Saarau both plastic clays and pure kaolins are found, while lean clays are mined at Schweidlitz and kaolin at Ruppersdorf. Neurode and Waldenburg (Altwasser) clays belong to the slate variety. In Prussian Saxony may be mentioned the kaolins of Halle from which the royal factory of Berlin draws its supplies; further, those of Bitterfeld, Elsterwerda, Salzmuende and Lettin. The Palatinate and Wurtemburg have clays of first-rate quality; in Bavaria those of Passau are valued for making crucibles. The Kingdom of Saxony is probably without a rival in its possession of fine clays, extending from Bautzen through Meissen to Leipsic. The Meissen clays are used for making the famous Dresden china. Kaolins and fire clays are found in Thuringia in the neighborhood of Coburg and Eissenberg. In Austria the finest kaolin is that of Zettlitz near Carlsbad in Bohemia. In Styria clays are found at Leoben. In France refractory clay is mined at Forges les Eaux, Montereau, while kaolins of Limoges make the well-known table china. In Belgium the best clays are found in the Ardennes. In England large quantities are mined and used at Stourbridge, Burslem and Newcastle; in Scotland, Garnkirk supplies material for the famous Glenboig brick. In Asia the most extensively mined clays are the deposits of China and Japan which have been famous since the Middle Ages.

A fire clay must have the following properties to make a satisfactory brick, form or vessel:

1. It must be infusible at high temperatures.
2. It must clinker, or at least become reasonably hard, when burned.
3. It must resist chemical agents.
4. It must not change its volume to any considerable extent at medium or high temperatures.
5. It must not suffer damage from change of temperature.
6. It must burn into a dense, strong and reasonably porous brick.

It is seldom, however, that all these demands are made on the fire-clay brick, and we would class as A1 such clays as would meet these requirements. For many purposes in many furnace operations a second-class fire clay which would meet only a few of these demands could be used, while third- and fourth-class refractories have also a wide use and sale.

Method of Mining and Winning Clays. — Prospecting is generally done by boring. Once the depth of the clay bed has been discovered and the material has been tested, we have the choice of stripping the overburden and recovering the clay by open-work mining methods, or, if the clay is too deep for this or not suitably situated physically, we may mine it by regular tunnelling or from shafts. These methods may be seen from Figs. 16 to 20, and Fig. 21 shows the interior of the mine with strata of clay. Coal and shale is shown clearly occurring above the clay, while the drill in the miner's hand marks the upper limit of the hard clay, the material between the drill and the roof being soft. Fig. 22 shows a vein of lean, hard flint clay on which the man is standing. Above it is an overburden of about 10 feet of soil and poor clay.

An excellent example of modern methods of mining fire clays is furnished in the clay pit "Guter Trunk Marie" at Rossbach in Hesse.*

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* *Thonindustrie Zeitung,* No. 97, p. 1168.

The property comprises several hundred acres of clay, quartzite and sand. Originally the fire clay on the property was mined by means of a number of isolated holes. Now, however, the greater development of the property has been made in the extensive open cut, exposing the different layers of materials. The overburden of disintegrated basalt, earth and poor clay extends 22 feet from the surface, followed by 5 feet of quartzite, 6 feet of basalt, sandstone and the clay bed of 90 feet, in the order named. The clay bed is composed of layers of argillaceous sand above, developing into a yellow fat refractory clay. Below this clay there is a thin bed of highly refractory blue clay followed by a bed of white clay, suitable for potter's ware.

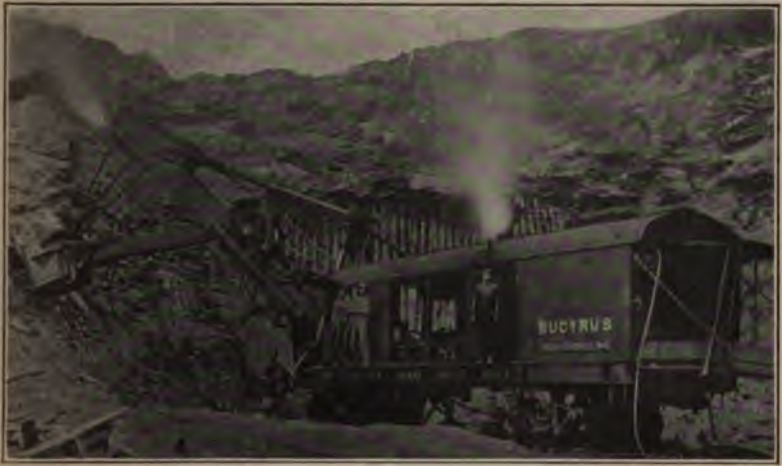

FIG. 16. — Mining Shale Clay.

A steam shovel clears off the overburden at the rate of 1000 cubic meters daily. The quartzite is blasted and picked, and the lower clay beds cut in terraces. The argillaceous sand is sold to steel works, the quartzite is made into silica bricks, and the fire clay is converted into refractory ware on the spot. A new plant replaces an old-fashioned Casseler furnace and consists essentially of three round downdraft kilns, each of which has a cubical content of 90 cbm. (100 cubic yards) and holds 90 tons of brick. The kilns have each 8 ordinary, natural-draft fire boxes and connect with a stack 170 feet high. The waste heat of the kilns is used for

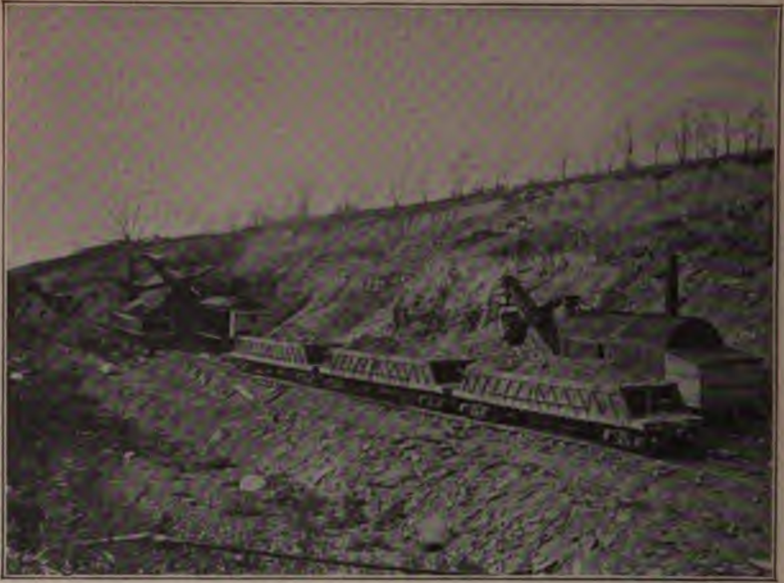

FIG. 17. — Stripping and Mining Shale Clay.

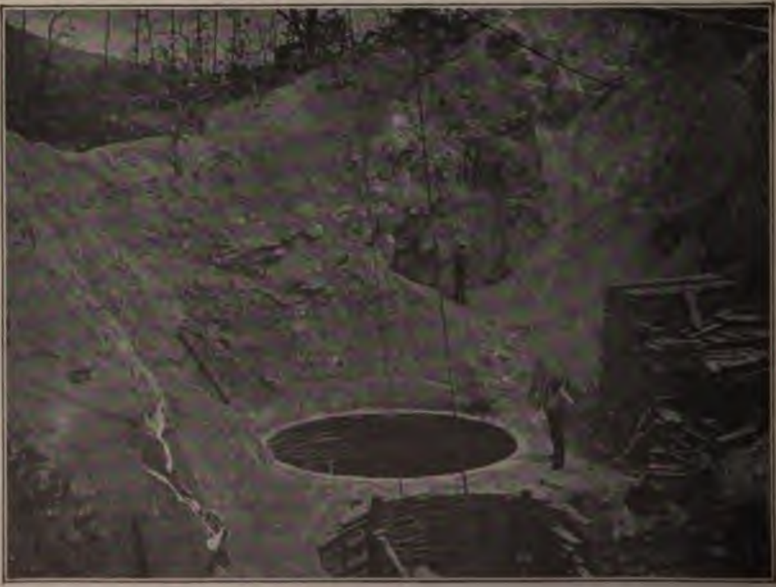

FIG. 18. — Mining Clay by Means of Pits.

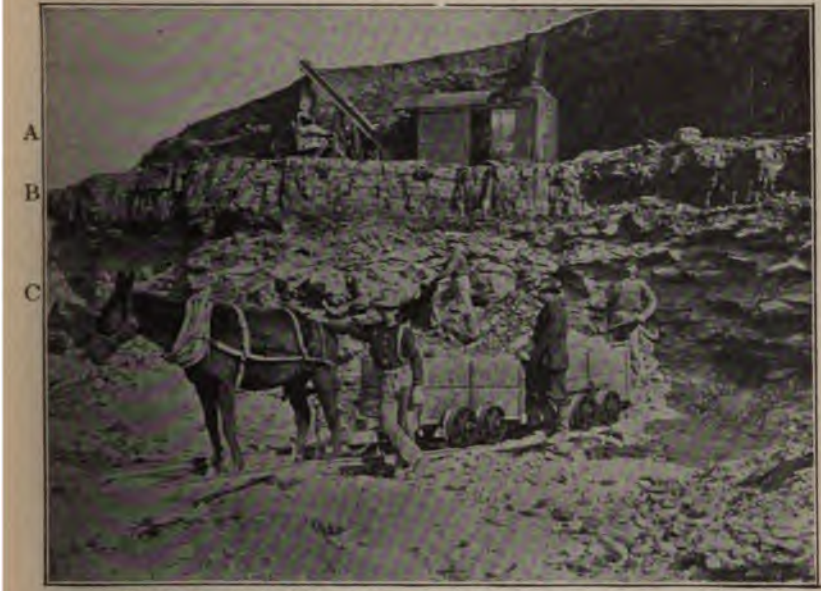

FIG. 19. — Bed of Fire Clay underlying Coal Seam (after Ries). (A, impure clay; B, coal; C, fire clay.)

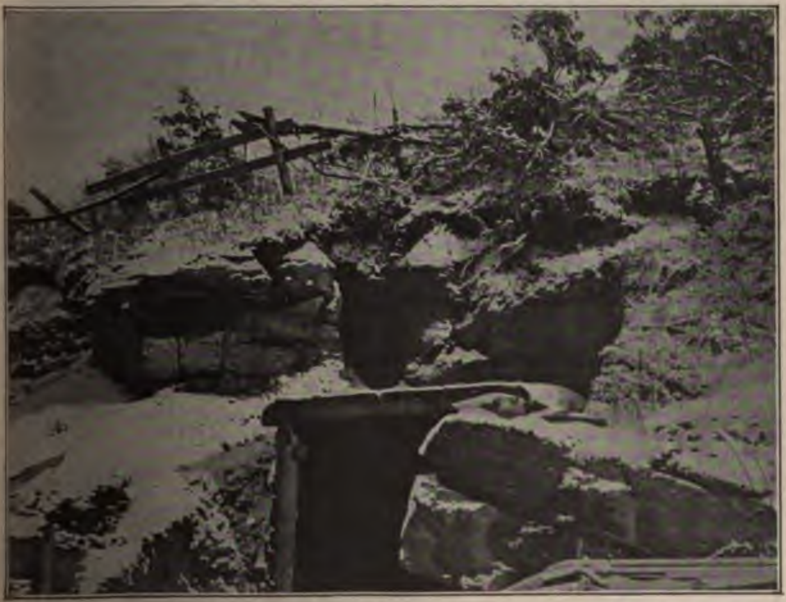

FIG. 20. — Fire Clay underlying Limestone (after Ries).

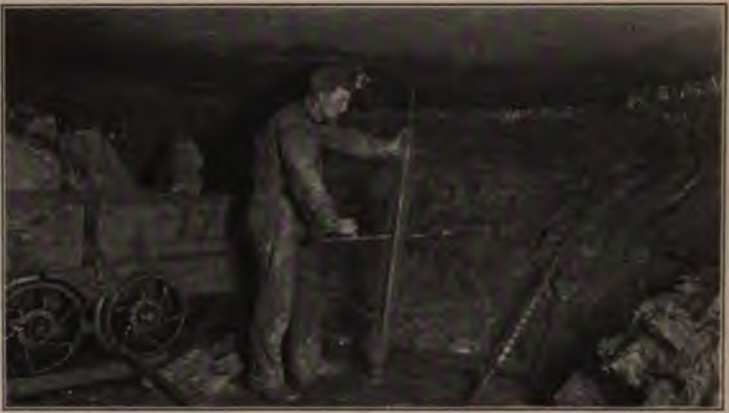

FIG. 21. — Mining Hard Clay underneath Coal and Shale Measures.

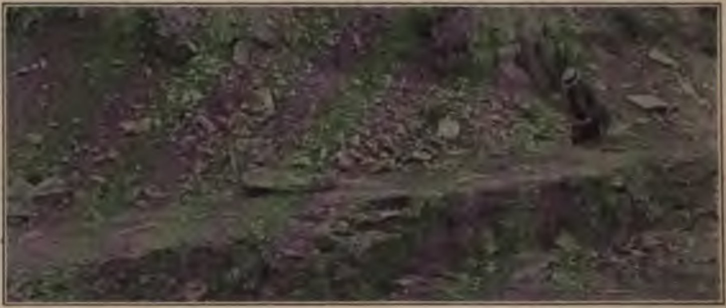

FIG. 22. — Lean Flint Clay underlying a Burden of Ten Feet of Soil and Poor Clay.

drying green ware. Plans are now made to install a ring furnace to burn chamotte for the trade. The appended analyses represent the quality of the different raw materials which are quarried in the pit.

	Clay. I.	Clay. II.	Clay. III.	Clay. IV.	Clay. V.	Argillaceous clay.		Quartzite.		
						Fat.	Thin.	*a.*	*b.*	*c.*
Loss	Dried	Dried	Dried	Dried	Dried	1.44	1.46	0.35	......	......
SiO_2	72.10	59.62	60.99	63.49	70.30	90.80	91.62	96.44	98.60	98.05
Al_2O_3	24.16	36.91	36.46	33.86	26.31	6.42	5.65	2.41	1.14	1.69
Fe_2O_3	1.55	2.11	1.51	1.22	0.90	0.45	0.69	0.66	0.30	0.31
CaO	0.36	0.18	0.29	0.14	0.55	0.23	0.54	0.05	......	......
MgO	0.34	......	0.12	......	0.13	......	......	......	......	......
Alkalis	1.49	1.18	0.63	1.29	1.81	0.66	0.04	0.09	......	......
Refractoriness according to cone	29	32–33	32–33	31	29–30	+30	+33	36	36	36

In Grossalmerode, in Hesse-Nassau, the overburden is removed and the clay mined in openwork by the terrace system. The height of the terraces has to the breadth the ratio of 1 to 3; not more than 18 inches horizontally of a terrace 5 feet high may be removed at a time. The old-fashioned way, still practiced in many places, is to drive a shaft to the clay, then simply gut out as much as is possible without endangering the lives of the miners. Often a number of these shafts are seen side by side. The material is raised to the surface by buckets on windlasses. In mining at depth the regular method of mining practice with shafts, drifts and stopes is used. In Stourbridge, Garnkirk and Pennsylvania the fire clay underlies the coal measures and is sometimes mined along with the coal. In other cases it is won by coal miners, who use the methods employed in collieries.

Where the deposit is sufficiently large and exposed, steam shovels of the bagger or clamshell types may be used. It is seldom, however, that fire-clay deposits are large enough to employ this method of mining. The raw material is divided into three classes, lean clay, plastic clay and grog. By "grog" we understand burned material, either old fire brick, retorts, crucibles and china or calcined clay. If the clay contains much water, carbonaceous material or limestone, or if the clay is to be used for shapes which may not shrink greatly in drying and burning, it is

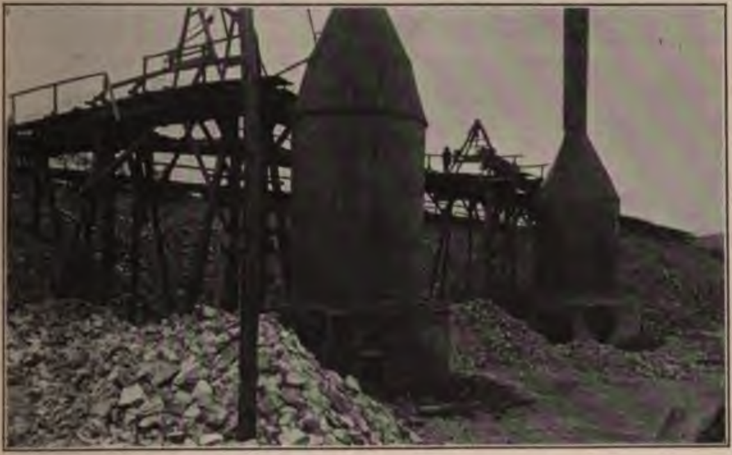

FIG. 23. — Two Kilns used in Calcining Clay.

calcined in a kiln generally situated near the mine. Fig. 23 shows the kilns used in calcining clay. The size of the clay as it comes from the mine is shown in Fig. 24. The lean, plastic and calcined clays are brought to the factory and stored in bins. (Fig. 25.)

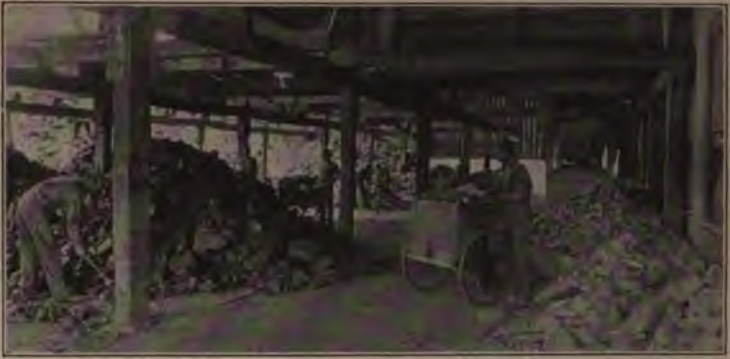

FIG. 24. — Making up the Batch of Lean, Plastic and Calcined Clays for the Wet-pan Grinding Machines.

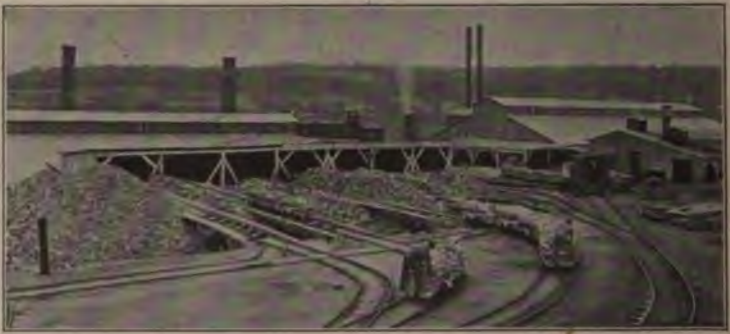

FIG. 25. — Method of Storing Clays.

Fig. 24 also shows the method of handling lean, plastic and calcined clays at the factory. The clay is broken by hammers, jaw crushers or gyratories and the good picked from the ferruginous or poor material. It is then thrown into buggies, which are divided by partitions of sheet iron. Each division is filled with its quota of lean, plastic, calcined clays and grog, in the proportions determined by the foreman or engineer for the manufacture of particular kinds and grades of brick. For good fire brick about

15 per cent of plastic clay is mixed with 85 per cent of lean clay. Calcined clay is added for shapes which are difficult to make. The process consists now in (1) grinding and tempering the clay in pan-grinding machines or in rolls; (2) in moulding and drying the bricks or shapes; and (3) in burning in kilns.

Pan Grinders.* — It is necessary to distinguish dry pans, wet pans and roller pans. Fig. 26 illustrates the standard 8½-foot dry pan for grinding dry clay, silica, magnesite, etc. The weight is 53,000 pounds; weight of crusher rolls 8500 pounds each. The drive is "overhead" through pinion and crown wheel; the material coming in is guided directly under the rolls, and as it becomes sufficiently ground escapes through perforated plates in the pan bottom. The ground material is kept from accumulating by means of the scrapers attached to the pan bottom which, as they revolve with the bottom, sweep the dust around to an opening in the flooring through which it falls on to a belt or other

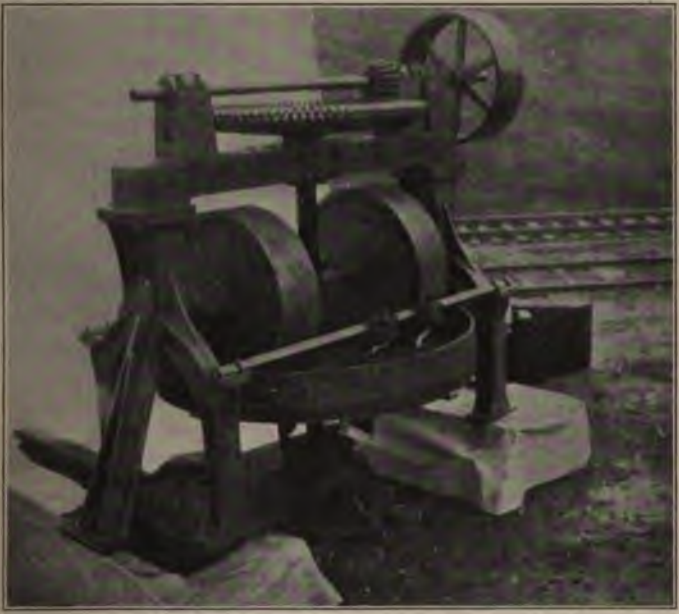

FIG. 26. — Dry Pan.

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* From information kindly supplied by the Clearfield Machine Shops.

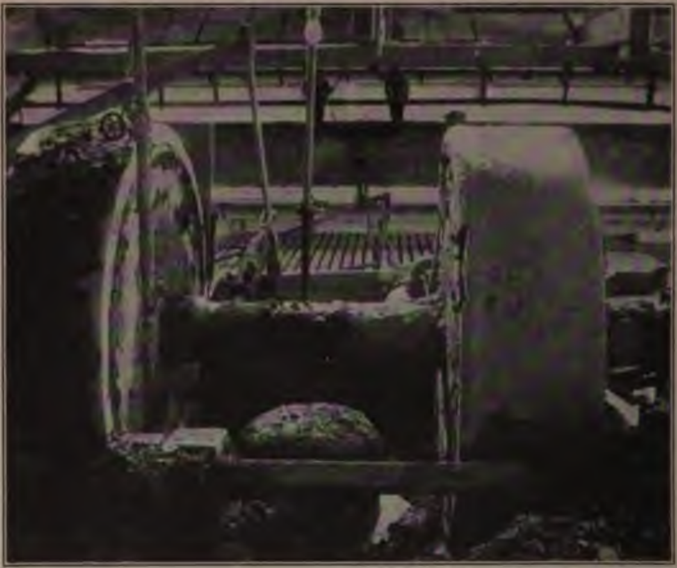

FIG. 27. — Wet Pan.

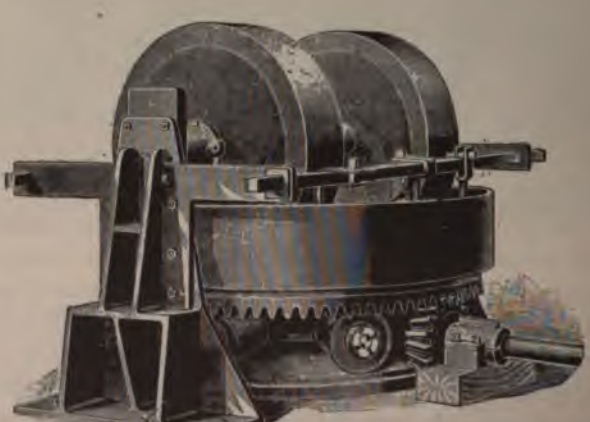

FIG. 28. — Wet Pan running on Six Rollers instead of in a Step.

device for carrying it to the point desired. In Fig. 26 the pan is set up in the open in order to show the parts beneath the pan bottom. In actual use the pan is so set that these parts are in a "step" or pit in the foundation below the level of the floor, and are covered on top by a false flooring which, as stated above, holds the ground dust. Set into this pit is the bearing or step box in which the vertical shaft ends and which supports the weight of the pan. This box is so constructed as to automatically take up wear and keep the vertical shaft in proper contact with the bearing plates upon which it rests. It also has adjustments by the use of which wearing parts may be readily examined or renewed without taking the machine apart in any way, and with the loss of only one or two hours' time.

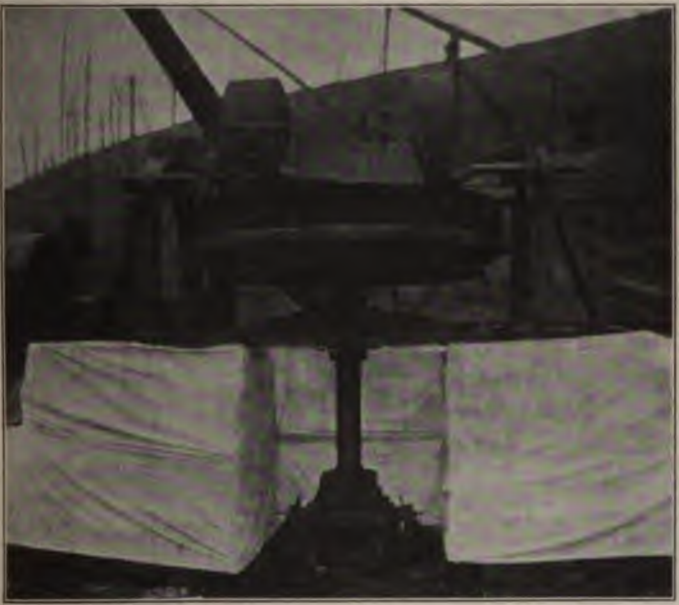

FIG. 29. — Wet Pan with Wynne Emptier.

The wet pans are made for grinding and tempering brick material at one operation, and are built in 7½-foot and 8-foot sizes. They are of two general styles — roller and step. The latter are either "overhead" or "under-driven," depending upon the location of the crown wheel. Fig. 29 represents an 8-foot step pan of the "under-driven" type. While in some respects it is similar to the dry pan there are several marked differences. Thus the step is deeper, accommodating a longer vertical shaft; the crown wheel is attached to the pan bottom, making the drive directly at the work and protecting the gearing. The "foundation plate" immediately beneath the crown wheel carries a bearing for the vertical shaft and a bearing for the horizontal or pinion shaft (both of which bearings are removable for refilling), so that vertical and horizontal shafts are necessarily kept in proper alignment, and the foundation itself is relieved of strain in operation. The pinion-shaft bearings have adjustments to keep the gearing in proper mesh.

The roller pan, Figs. 27 and 28, is a wet pan constructed to run on six (6) conical rollers instead of in a step. These rollers support the weight of the pan and are held beneath the bottom by a "spider," the arms of which form the shafts of the rollers.

Fig. 29 shows a wet pan with Wynne pan emptier attached. The latter is a device for removing ground clay from the pan and is adaptable to any standard wet pans. When the end of the emptier blades is let down into the pan, the clay is shot up over the side of the rim on to moulding tables or into buckets, elevator or cars, as the case may be. The use of this attachment increases the capacity of the pan.

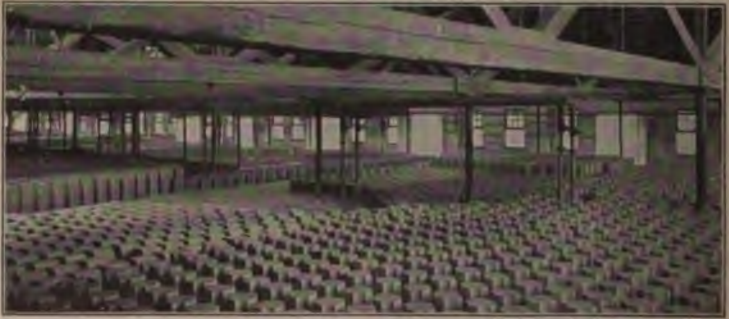

Fig. 30. — Difficult Shapes drying on Hot Floor.

The clay may be ground in disintegrator rolls or in pan grinders. The wet pans are the most widely used in the United States. The right quantity of water to make the clay temper and mould is added in the pan or to the mass after it has passed the rolls.

This is then moulded into bricks or shapes either by hand with wooden or iron moulds, or by hydraulic or hand presses.

Irregular shapes are dried on a "hot floor" heated by warm air blowing down upon them or by steam pipes lying in or under the floor.

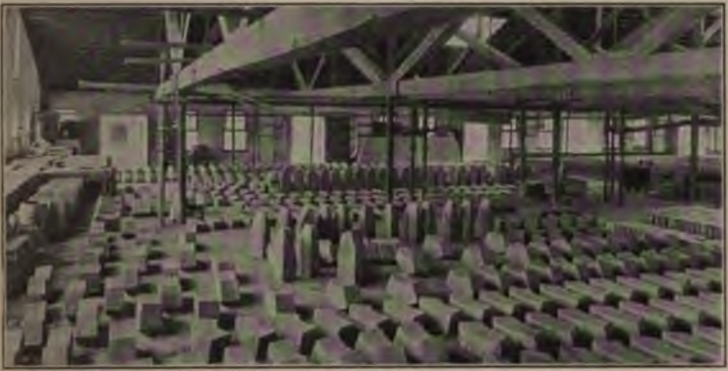

FIG. 31. — Difficult Shapes on Drying Floor.

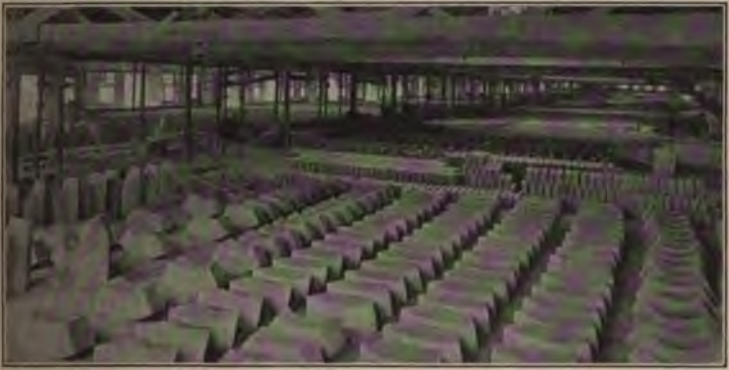

FIG. 32. — Difficult Shapes on Drying Floor.

The process of drying lasts from 15 to 50 hours. Fig. 30 shows in the foreground material for converter bottom, in the background hexagons for converter bottoms drying on the steam-heated floor. Figs. 31 and 32 show some coke-oven shapes drying.

After the brick has dried for some time either on a hot floor or in a drying tunnel, heated by steam or hot air, they are often repressed as shown in Fig. 10. It has been found good practice to use the waste heat of the kilns to produce steam for the drying tunnels and floors, and to apply the hot air from the kilns which are cooling for drying the brick on the hot floor. The bricks are now ready to be burned.

Burning Bricks in Kilns.* — The kilns generally used in the United States are of two kinds: (1) the downdraft type with Parsons' forced-draft or ordinary natural-draft firing, in which the heat from the fire boxes is drawn from the bottom to the top of the kiln and then down and out from the center of the floor. Parsons' fire box uses a draft forced with steam; (2) the old-fashioned updraft kiln, in which the heat rises straight up from the fire box through the kiln and is drawn off near the top of the stack. The downdraft kiln is generally circular, 15 to 20 feet in diameter, and 12 feet high at the periphery. The updraft kilns may be either round or rectangular in plan. Fig. 33 shows the inside of a rectangular updraft kiln and the method of laying bricks and shapes for burning. The process of burning is divided into three stages: (1) dehydration, or water smoking; (2) oxidation; (3) vitrification. In all these stages the draft and temperature must be carefully regulated with a view to obtaining the best possible distribution of heat throughout the whole kiln and an even and gentle rise in temperature. These operations are controlled carefully by water-pressure gages and Seger cone, thermoelectric, or optical pyrometers.

Water Smoking Period. — The first stage of the burning is that of the removal of the hygroscopic water. While it is necessary that the rise in temperature should be slow during this period, too much time spent in water smoking may seriously reduce the capacity of the plant. Slow evaporation within insufficient draft may produce scum upon the brick, particularly if the fuel contains sulphur or if the clay has much potash, soda, lime or magnesia. A moisture-testing rod should be used to determine the rate of dehydration. This is simply an iron rod which is inserted in the kiln. If water is still present it will be visible on withdrawing the rod. A large excess of air is needed during this period of from three to four days which are spent in water smoking. The temperature rises to 500° F. and the draft to 4 mm. Coke is more satisfactory than most fuels in this operation since the heat may be more evenly controlled.

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* See Richardson, "Burning Brick in Downdraft Kilns."

The Oxidation Period. — This period extends from the stage at which the hygroscopic water has been completely driven off to that at which the shrinkage of the clay, or settling of the brick, begins. Lower oxides of iron and manganese are oxidized to the higher forms; carbon is burned to carbon dioxide and this and the carbonic acid of the lime and iron of carbonates is expelled, while dehydration of chemically combined water in the kaolinite is effected. The brick obtains a bright color, generally buff, some time before the temperature of 1500° F., which marks the limit of the heat of the oxidation period. The fourth, fifth, sixth and seventh days are employed in the oxidation period. The temperature rises from 500° to 1500° F., and the draft sinks somewhat (from 4.2 mm. to 3.7 mm.).

The Vitrification Period. — During this period the clinker is formed. By this we understand the particles of slag which are made by the basic oxides combining with silica and alumina throughout the brick. These hold the particles of the burned clay together and in shrinking make the brick porous and produce the effect of clinkering, that is to say, the brick becomes hard and rings when struck with a hammer. At the close of the oxidation period the bricks are uniform in color, and will have begun to harden but they are too soft for any useful purpose. The kiln doors are now kept tight, but little excess air is allowed in the kilns, and the temperature is driven up to 2700° F. or even 3000° F. The finishing temperature can be determined by the Seger cone, but the progress is best ascertained by measuring the amount of settle, that is to say, the number of inches the bricks have sunk in the kiln owing to their shrinkage.

Vitrification commences with the beginning of the eighth day as a rule, and is completed at the end of the twelfth day. The draft is reduced gradually from about 3.7 to almost 2 mm., and the bricks settle from an inch, which is recorded at the end of the oxidation period, to ten to twelve inches at the end of the twelfth day. When the proper settle has been obtained and the proper cone has melted in the kiln, firing should cease. The dampers should be closed when all the fuel has been burned out, so that the bricks may be allowed to cool slowly and evenly. The harder and more dense the bricks, the more liable they are to be damaged by uneven cooling. In fact, the brick must be annealed during the process of cooling. When the kiln has cooled to a temperature of from 300° to 500° F., a fan may be attached and cold air blown into the furnace to enable the workmen to enter and remove the bricks. When the kiln is opened and the bricks are removed, examinations are made as to the condition of oxidation and the distribution of temperature in the kiln. The amount of settle is measured and the poor bricks rejected on removal of all from the kiln.

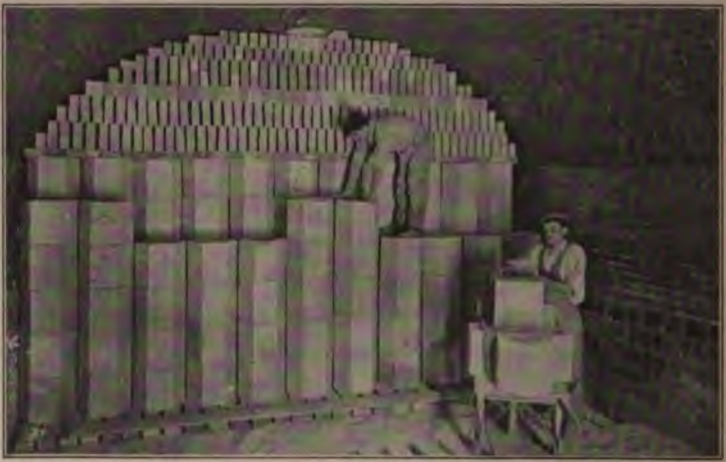

FIG. 33. — Setting Difficult Shapes in a Kiln.

In burning fire-clay bricks, hollow ware and special shapes, the heat must be raised gradually and maintained at the highest temperature desired, long enough for the heat to penetrate to the interior of the form. The smaller this is, so much the quicker, more evenly and homogeneously will it burn. In the case of larger shapes, it is not possible for the interior to attain the same temperature as the surface. Accordingly they are clinkered to a certain depth by being kept for longer periods at a high temperature. Fig. 33 shows the manner in which large hollow shapes are set in a kiln. This particular kiln is of the updraft type; the shapes are hollow hexagons for hot-blast stoves.

In Germany the individual round or rectangular kiln has given place to the chamber furnaces of the Hoffman or Mendheim type.

These are fired either with producer gas or half gas from the Siemens' fire box. The chamber furnaces are generally elliptical in shape with a chimney in the center. The elliptical furnaces are divided into a number of chambers by means of partitions of sheet iron, and all the fuel value of the gases will be realized by vitrifying in one kiln, dehydrating in another, and drying brick in another before they eventually pass out to the stack. The American system of Parsons' firing is replaced by Siemens' or Boetius' half-gas firing, and again the waste heat from the kiln in which the bricks are vitrifying is realized in the other kiln. Another type of kiln is the three-storied furnace, in which the heat from the bottom or burning kiln arises to the middle or dehydrating chamber, and from there to the uppermost or drying oven. The Mendheim furnace utilizes the waste-heat gases by conducting them through regenerative chambers. The method of firing is that of using on two sides of the furnace Siemens' air-gas producers and warming the air for the combustion of the gas by leading it as a counterstream through the generators which are being heated by the outgoing hot gases. This is depicted in Figs. 34 and 35.*

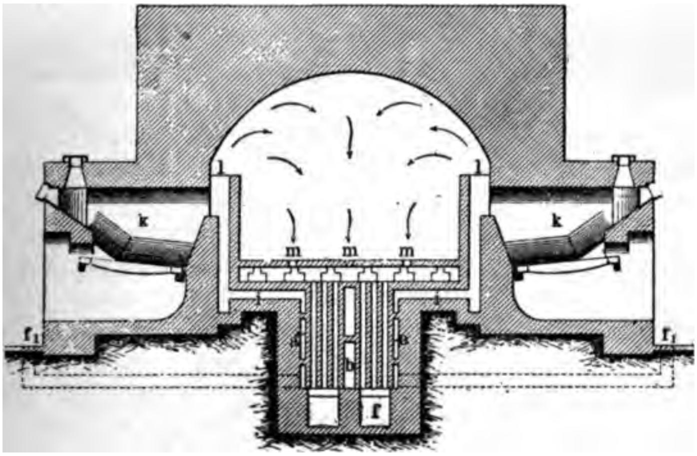

FIG. 34. — The Mendheim Kiln with Regenerator.

In construction care must be taken that no moisture from the earth will rise into the kiln. Accordingly, the foundations are

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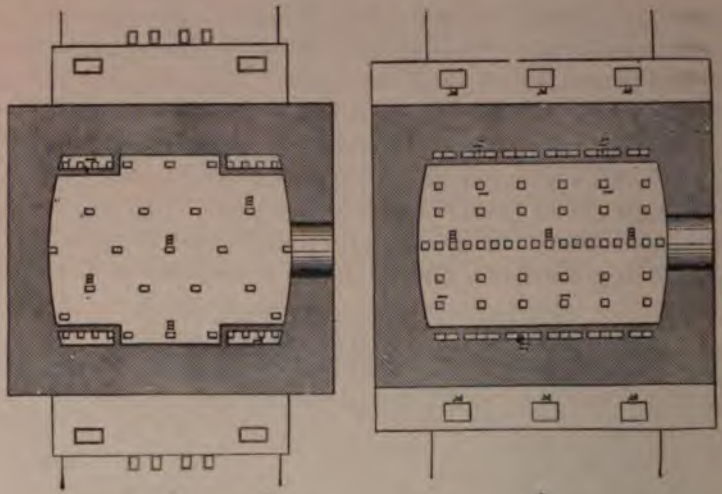
* See Kerl, *Handbuch der Gesammten Thonwaarenindustrie*, pages 425 et seq. and 847-876.



a. *b.*

FIG. 35. — Two Types of Mendheim Kilns.

(The fire gases enter the kiln at *l* and leave at *m*. In *b* the fire gases enter through the floor of the kiln.)

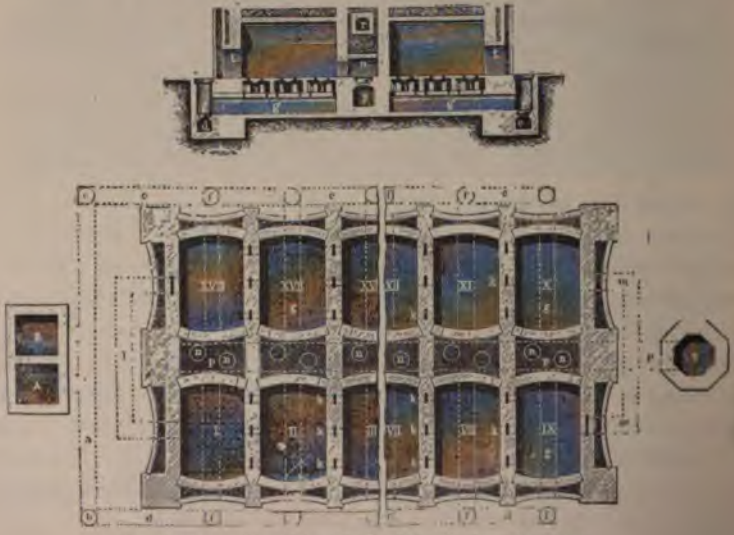


FIG. 36. — The Mendheim Multi-chamber Kiln.

(The producer gas from *g* meets, in *i*, air which has been preheated in one of the burned chambers, and, mixing with it, burns on rising into the chambers to which it is directed by means of a system of dampers.)

laid deep in the excavated ground, and consist of old brick or stone. An insulating layer of coke breeze or sand is laid beneath the floor of the kiln proper. The walls are made of clay brick and securely anchored with strip iron held together with turn buckles. The dome is generally made of fire-clay brick, although silica is also used. This may be made double with a hollow space between the two brick domes, which may be filled with an insulating material. In most modern American plants the kilns are built in such a position that their waste heat may pass around the tubes of the boilers and produce steam for the Parsons' fire boxes and for the drying tunnels and floors. Another furnace used for burning refractories is the Casseler oven. This is similar to a long American kiln and has fire boxes at one end only. In this long flaming coal should be used for firing. The Casseler and the Mendheim furnaces have proved the most economical of all. According to Kerl the Mendheim furnace used 8 parts coal; the Casseler furnace 9.5; a battery of downdraft kilns, with waste-gas flues connecting either with one another or with the stack, used 11; and a two-storied round updraft kiln, with step grates, used 16 parts of coal per cubic meter of efficient furnace content.

Fire clay is used most generally and extensively in industrial furnaces, in blast furnaces, crucible melting furnaces, the layers and bottoms of Bessemer converters, the furnaces used in the lime, glass, clay and cement industries, in lead-refining furnaces, in the shafts and crucibles of copper and lead blast furnaces, in basic open-hearth furnaces above the slag line, for general metallurgical reverberatory furnaces, flues, boilers, settings, linings of stacks, household grates, in incinerating furnaces, regenerative checkers, etc. Certain shapes are especially manufactured for hot-blast stoves, converter bottoms, coke ovens, both for the Solvay, Hoffmann and beehive types, for crucible furnaces, etc. A number of these unusual shapes are shown in Figs. 30, 31 and 32.

Several producer gas-fired kilns of the continuous type have been developed in America within recent years. An example of these is the Youngren, which can be arranged either as a compartment or as a tunnel kiln. The latter type will answer for only lower grades of ware and has a capacity for 35,000 standard-sized bricks a day, while a compartment [illegible] proper apparatus for the burning of the more refractory kinds of clay ware. This may be built to handle 100,000 bricks a day. It consists of:

1. The gas-producer plant.
2. The kiln.
3. The stack or fan.

The kiln consists of from 12 to 18 or 20 compartments, and is constructed of two unit batteries with an even number of compartments. The main draft flue is placed under and between these two batteries. The green ware is brought from the drying tunnels on tracks laid above and between the two batteries. The compartments of the kiln are similar in arrangement to square, downdraft kilns. The flame issues from flash walls, travels down through the ware and then through a perforated bottom into the bottom flues, whence it passes through openings at the bottom of the partition walls to the next compartment. Thus the total value of energy is realized by the gas passing on from one chamber or compartment to another until all the realizable heat has been used up. The gases are then drawn from the bottom flue into a collecting flue which leads to the main draft flue. If there is any heat left in them it may be used to heat boilers. The main gas flue is placed on the top and outside of each battery. Between the crowns of each two compartments the gas-distributing flue is situated. This connects with the main gas flue on the one side and on the other opens up into pockets left in the partition walls, whence it issues into the layer behind the flash walls, mixing and entering into combustion with the secondary air. This arrangement affords means for drawing warm air from a compartment which is cooling, for a compartment in which the bricks have just been set up and hot air from another cooling compartment to ware which has already attained a medium temperature. The gas producer recommended is that of the water-sealed type, in which the fuel bed rests on the ashes lying in the water pan. The air is blown by a steam injector into a cylindrical chamber resting on the center of the water plant. This air chamber is covered by a conical perforated grate. It is claimed that the water-smoking period is more easily controlled by using gas, and that less scum is formed owing to the regulation of the draft, temperature and excess air, and of the sulphur and other noxious contents of the gas.

Fig. 37 illustrates this kiln. Up to the present time it has not found its field so much among the first-class refractory brickworks as in clay and tile and the less infusible brick factories.

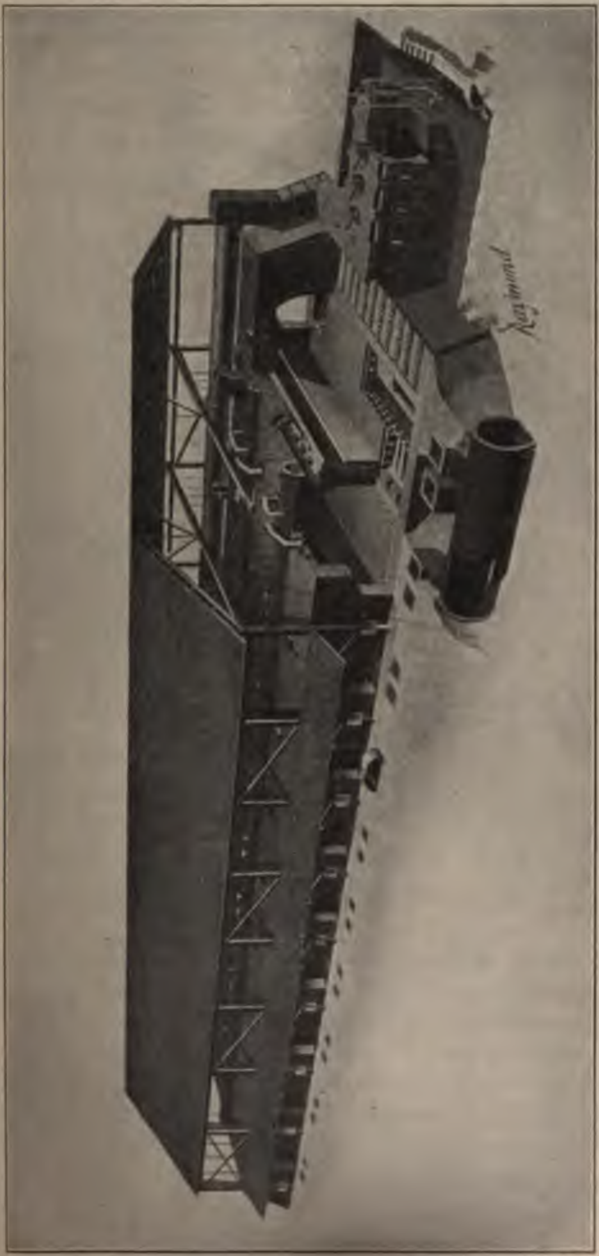


FIG. 37. — Youngren Kiln.

Temperatures Employed in Burning Brick and Clay Wares *

	Cone.	Temperature.	
		°F.	°C.
Porcelain colors and lusters	022 to 010	1094 to 1742	590 to 950
Common building bricks, drain tile, stove tile and the like, iron- and lime-bearing clays	015 to 01	1472 to 2066	800 to 1130
Roofing tile	010 to 1	1742 to 2102	950 to 1150
Art pottery Biscuit	05 to 1	1922 to 2102	1050 to 1150
Glaze — glossy	010 to 2	1742 to 2138	950 to 1170
matte	05 to 4	1922 to 2210	1050 to 1210
Sewer pipe from shale	05 to 1	1922 to 2102	1050 to 1150
Common cream bricks from limey clays	03 to 2	1994 to 2138	1090 to 1170
Paving bricks from shales	1 to 4	2102 to 2210	1150 to 1210
Sewer pipe from fire clay	1 to 8	2102 to 2354	1150 to 1290
Whiteware pottery Biscuit	3 to 10	2174 to 2426	1190 to 1330
Glaze	010 to 10	1742 to 2426	950 to 1330
Face brick from fire clay	3 to 10	2174 to 2426	1190 to 1330
Floor tile Encaustic	4 to 7	2210 to 2318	1210 to 1270
Vitreous	7 to 10	2318 to 2426	1270 to 1330
Paving bricks from fire clays	4 to 8	2210 to 2354	1210 to 1290
Stoneware, with salt or slip glazes	5 to 10	2246 to 2426	1230 to 1330
Fireproofing	1 to 8	2102 to 2354	1150 to 1290
Fire brick, cement and porcelain	10 to 20	2426 to 2786	1330 to 1530
Glass tank blocks	10 to 20	2426 to 2786	1330 to 1530
Gas retorts	15 to 20	2606 to 2786	1430 to 1530
Silica brick and hard-flowing glazes	20 to 26	2786 to 3002	1530 to 1650

Drying shrinkage of clays	1 per cent to 10 per cent
Burning shrinkage of clays	0 per cent to 8 per cent

* From W. D. Richardson, *Burning Brick in Downdraft Kilns*, and Kerl, *Handbuch der gesammten Thonwaarenindustrie*.

Home-made Bricks. — In remote districts ordinary building materials are often lacking. Where labor is cheap it is frequently possible to secure a fairly serviceable home-made brick when a suitable clay deposit can be found in the neighborhood. Excellent bricks can be made even by inexperienced men.* The directions given by a writer in the *Engineering and Mining Journal* are: Puddle the clay well, but do not add enough water to make it so plastic that it loses its shape when left unsupported. The moulded bricks should be allowed to dry slowly in the sun. For burning dig a pit 6 feet square and 6 feet deep. Heat the bottom and sides by a dry brushwood fire, stack the bricks leaving spaces between them and fire at the top with a brisk brushwood fire for 30 to 48 hours, according to the time found necessary by trials. The bricks so burned will include a smaller percentage of "white-washed" and "hard-burned" bricks than is usually obtained in kilns. Three men, a puddler, a moulder and a stacker should mould 500 bricks in 8 hours, when bricks are made by hand.

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* *Engineering and Mining Journal*, April 29, 1911.

To test clay for brickmaking, puddle it well with a little water, let it dry slowly in a shady place, then burn in a forge. If the brick shrinks or cracks badly, fine sand should be added to the clay to temper the mixture.

The adobe bricks made from mud and water, particularly those in dry climates which carry a content of alkali salts, are often suited for walls, small "shacks" and even flue walls as well as workmen's huts.

CHAPTER V

THE PREPARATION OF THE BASIC AND NEUTRAL REFRACTORIES

Magnesia, Steatite, Chromite, Bauxite, Carbon, Carbon-Silicon Compounds, Asbestos and Various Metals. — The most important of these is magnesia, the product of burned magnesite. It is probably the most widely-used refractory, with the greatest possibilities of more varied application, and yet often most disappointing to the baffled operator. Some magnesia products spall at fairly low temperatures, crack when a metal bath laps against their sides or crumble when subjected to changes in temperature, while others withstand such tests and also the influences of high temperature and active slags. This varying conduct is due to differences both in the chemical composition and in physical structure of the raw materials, and also to the method of grinding, tempering and bonding and to the conditions governing the drying and burning. Within the last few years, with growing knowledge of its physical properties, the preparation of magnesite for the industry has been more careful. The results have been such that the application in different fields is growing rapidly. The magnesia-bearing minerals, magnesite, serpentine, soapstone and steatite, have been used for many years, in the raw, calcined and prepared state, as fettling for furnaces, either alone or in mixtures with such additions as fire clay. For instance, in Europe Styrian magnesite has long been used in an admixture with fire clay; from the mixture, bricks have been formed, burned at a high temperature and used in iron, glass and other industries. Serpentine, containing 44 per cent SiO_2, 43 per cent MgO and 13 per cent water, was a favorite lining for basic charges in Styria. Even for the linings of the old puddle furnaces of Dornawitz, magnesia bricks were regarded with favor.

The best-known deposits of relatively pure amorphous magnesite are those of Euboea in Greece, of Silesia, Hungary, Norway, India and California. For the manufacture of modern bricks the crystalline spathic magnesite of Styria, prepared by the firms of Veitsch and Spaeter, is especially desirable. Efforts have also been made to use, in preparing magnesia, the by-products from the salt industry such as magnesium chloride.

The value of magnesia in the form of mass, bricks and crucibles depends on the infusibility and resistance to chemical action of pure magnesia. Now, commercially pure magnesia may be obtained only by calcining magnesite at very high temperatures. The material, obtained by calcining in the electric furnace at 2000° C., is a very satisfactory product and, when made into bricks, or crucibles, has a relatively longer life when exposed to the influences of severe heat and chemical attacks. A crucible, made by moulding the ordinary magnesia resulting from incomplete calcination of magnesite in industrial furnaces, when subjected to a temperature of 2000° C., sinters so that the walls and bottom become dense and tough. That same crucible will soften again and become difficult to handle when exposed to any high temperature. The ordinary magnesia bricks are burned at a temperature which turns cone 29 (1710° C.). It is a satisfactory refractory material in the lining of a commercial furnace which works at or below a temperature of 1600° C., but softens and spalls when subjected to a high temperature.

It always has a tendency to combine with acid materials but becomes particularly active at high temperatures. Accordingly, any tests to determine the temperature of softening, or other qualities of magnesia, should be made in a magnesia or neutral vessel, since it fuses at a lower temperature than the real softening point when in contact with fire clay or acid material with which it forms a relatively fusible salt. With regard to the influence of the physical and chemical properties of the raw material, it is interesting to note that the Styrian magnesite is generally held in higher regard by refractories manufacturers than the Grecian mineral. The Styrian is a crystalline or spathic mineral; the Grecian magnesite is found in an amorphous mineral. The former contains more impurities, especially peroxide of iron. The particular combination of impurities present in the Styrian variety serves, in burning, to sinter and knit the whole brick or other shape together, just as the basic impurities in the Pennsylvania and Wisconsin quartzites help, by their combination with silica, to cement the whole brick or form together. The special value of the crystalline structure depends on the mineral grinding to a grain of heterogeneous form, whereas the amorphous mineral, on crushing, falls in part to dust. The fine dust particles or even grain are difficult to hold in bond. The following analyses represent the chemical composition of different kinds of magnesite.

Analyses of Samples of Magnesite

	1	2	3	4	5	6
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
$MgCO_3$	94.46	95.12	92.52	90.30	42.43 MgO	46.04 MgO
$CaCO_3$	4.40	4.02	3.55	0.05	1.68 CaO	1.22 CaO
Fe_2O_3	0.08	Trace	3.79	4.49	3.53	2.48
Al_2O_3	......	......	....	1.40	0.03	....
SiO_2	0.52	0.52	0.14	....	0.92	....
Water	0.54	0.34	....	....	....	....
MnO_2	......	......	....	....	0.53	....
Loss on ignition	......	......	....	....	50.41	49.15
Insoluble	......	......	....	3.73	....	2.40
	100.00	100.00	100.00	99.97	99.53	101.29

	7	8	9	10	11	12
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
$MgCO_3$	90-96	87-99	94.80	46-48 MgO	66.13	46.00 MgO
$CaCO_3$	0.5-2.0	1.5-2.6	0.10	0.6-0.7 CaO	7.60	0.85 CaO
Fe_2O_3	3-6	......	3.2 (FeO)	1.5	10.90	1.62
Al_2O_3	......	......	1.1		....	
SiO_2	0.1	0.6-4	0.8	4.5-5.25	....	0.30
Water	......	......	....	....	....	....
MnO_2	0.5	......	....	....	....	....
Loss on ignition	......	......	....	46-50 (CO_2)	....	51.23 (CO_2)
Insoluble	......	......	....	....	4.07	....
			100.00		99.64	100.00

1. Euboea.	4-6. Styrian.	9. Hungarian.	11. Lapland.
2. Euboea.	7. Styrian.	10. Silesian.	12. Ural.
3. Styrian.	8. Styrian.		

Analyses of Calcined Magnesite

	1	2	3	4	5	6
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
MgO	82.46-95.36	85.30	88.22	84.20	86.85	70.21
CaO	0.83-10.92	1.76	0.87	2.25	2.26	7.95
Fe_2O_3	0.56- 3.54	7.79	7.07	8.40	8.46	14.19
Al_2O_3		0.82	0.86	.....	.....	.....
SiO_2	0.73- 7.98	3.40	2.35	2.50	0.85	.....
MnO_2	....	.....	0.59	0.72	0.46	.....
CO_2	....	.....	.....	0.50	0.35	.....
Insoluble	....	.....	.....	1.30	.....	7.09
		99.07	99.96	99.87	99.23	99.63

1. Greek from Mantudi, average of four analyses. (*Thonin.-Ztg.*, 1893, p. 142.)
2. Styrian sinter magnesite. (*Thonin.-Ztg.*, 1893, p. 143 and 1901, p. 1919.)
3. Same. 4-5. Same dead burned. 6. Lapland, burned.

[*Handbuch der gesammten Thonwaarenindustrie*, von Bruno Kerl, pp. 909-[illegible].]

Preparation of Magnesia Brick. — The processes of preparing magnesia for the market vary in Styria and Greece. The better part of the Styrian industry is in the hands of the American Refractories Company and the firms of Veitsch and Spaeter which sell to the German steelworks, to Messrs. Harbison-Walker and the general trade. The mineral is mined, for the greater part, in open pits and terraces by means of steam and hand shovels. The magnesite is calcined at the mines, but strangely enough no attempt is made, either in Styria or Greece, to recover the carbonic acid, of which magnesite produces more per ton of material than any other common carbonate mineral. There is a distinction made between the calcined magnesite and the dead-burned magnesia. In making the first named, the material is calcined at a temperature of about 800° C., or red heat, when the greater part of the carbon dioxide escapes. This is the material used by the American refractories manufacturers. To effect this calcination, rotary calcining furnaces, Mendheim and Schmatolla kilns and vertical shaft kilns are used.

The American Consul General in Greece has kindly given the following information on the Magnesite Industry in Greece.

"Three companies are engaged in mining magnesite on the island of Euboea and elsewhere. These are the Anglo-Greek Magnesite Company, The Holland-Greek Magnesite Company and the Society of Public Works of Athens. The product of these three companies in 1909 totaled 74,462 tons, of which 17,665 tons were exported in the raw state; the remaining 56,797 tons were converted into 15,394 tons of calcined magnesia, 1507 tons of dead-burned product and 552 tons of bricks. The quantities sold in 1909 were as follows: Calcined, 14,716 tons, dead-burned 1893 tons and bricks 294 tons.

The value of the total quantity mined was estimated at Drachmas 1,522,215 (1 Drachma = $0.193).

The ore was won both from open-surface pits and by underground mining.

In burning the magnesite three different kinds of furnaces were used. These are the "Schmatolla," the "Mendheim" and bottle kilns.

The best ore is mined in the province of Locris; it contained 96 per cent carbonate of magnesia and when burned produces caustic magnesia w [illegible] cent MgO. The approximate composition of the other Greek magnesite ore is from 94 per cent to 96 per cent carbonate of magnesia, 2 to 3 per cent silica, 1 per cent lime, with a little iron and aluminium oxides.

The Greek magnesite is used only for making refractory mass and materials; no carbonic acid is made in Greece from the magnesite."

Magnesite must be subjected to a final temperature of 1800° C. to become dead burned. This material is, however, different in properties from that calcined at electric-furnace heat. The product of the electric furnace is not hygroscopic, and is so thoroughly shrunk that, when made into brick form, it may be used in arches and other parts of a furnace structure where the engineer is somewhat loath to use the material burned at the lower temperature. The ordinary magnesia brick is the result of two calcinations. The first is the calcination of the raw magnesite which, in the case of commercial brick, is done in Styria; the second, that of the burning of the imported magnesia, after it has been pugged and tempered in the dry pan, moulded and dried. The pure MgO commences to soften at about 2000° C., becomes more plastic with increase of temperature and is viscid at 2500° C. It never becomes really fluid.* O. P. Watts, in attempting to find a eutectic of lime and magnesia, made a number of mixtures of the two oxides, but no one of them softened at a temperature lower than the softening point of magnesia. Goodwin † gives the melting point of magnesium oxide as 1910° C., Lampden ‡ as 2000° C. and Hempel § as 2250° C.

It certainly does not soften below 1890° C. The temperature of softening of calcium oxide is placed at 2040° C.||

All magnesia bricks have the property of softening at very high temperatures (white heat) and losing their coherence. On account of its property of sintering at high temperatures without actually fusing, due to the proper quantities and combination of bases and acids contained in the impurities (ferrous oxide, silica and alumina), the Styrian magnesite is often preferred to the purer Greek mineral which must be burned either at a higher temperature, or with some ingredients which will effect the sintering at lower temperatures.

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* Private communication.

† *Transactions of the Electrochemical Society*, Vol. 9, p. 89.

‡ *Journal of the American Chemical Society*, Vol. 8, p. 852.

§ Wright, "Electric Furnaces," p. 229.

|| Stansfield, "The Electric Furnace," p. 50.

To burn the Grecian magnesite dead the calcined material must be heated to a higher temperature (1700° C.) when the purer kinds contract and become dense, hard and friable. Such magnesite as the "Veitsch," however, will sinter under such conditions, owing to incipient slagging, due in greater part to the iron content, of which about 3 per cent is the desirable limit. With more than 4 per cent of iron, magnesite sinters too readily and becomes too fusible.

In burning magnesite, cupolas, reverberatories and calcining furnaces of the shaft (lime kiln), shelf and continuous Hoffmann type are used. For heating, solid or gaseous fuel may be used. The gas-fired Mendheim chamber furnace and the Siemens' gas reverberatory are favored vessels for the operation; when the former is employed, the hearth is stamped with fine magnesia, thus protecting it against the slagging action of the calcining magnesite. The greater part of the fire gases is introduced into the chamber above the charge; it is then drawn through to the hearth flues which are made of the raw magnesite and is conducted to the next chamber where it pursues a similar course. Some of the fire gases are introduced directly into the hearth flues where they mix with downcoming gases from the charge and promote a homogeneous calcination of the whole bed of magnesite. The temperature required amounts to 1850° C. (Seger cone 35) for the dead burned. The long cylindrical rotary calciner (60 feet long by 6 or 7 feet in diameter) is now being used for calcining.

The Manufacture of Grecian Magnesia Bricks. — Bricks prepared from Grecian material may be made by burning a mixture of dead-burned and caustic magnesia without any other admixture. The proportions vary from 1 to 50 per cent of caustic to 100 per cent of dead burned. The larger the proportion of caustic the easier it is to shape the bricks, but the greater the contraction on burning the brick. In using smaller percentages of caustic, tar or other binder such as magnesium chloride may be used. The ordinary bonds used in the magnesia brickworks are tar, thick and free from water, gelatinous silica, boric acid, caustic alkalis, soda, clay, blast-furnace slag, mixed with salt and various mixtures of carbolic acid with alkalis.

Considerable mechanical tenacity may be imparted by an addition of ferrous oxide or of silicates, while starch or sawdust makes the ware porous. Serpentine is sometimes used as a bond in Greece. To form the bricks the mass is first hand moulded and dried and then the bricks are subjected to hydraulic presses with a pressure capacity of as much as 400 tons.

Drying is effected slowly to prevent cracking. After thoroughly drying the bricks are placed in the burning furnaces, generally either reverberatory or Mendheim furnaces in Europe and downdraft kilns with Parsons' or ordinary draft firing in America.

Preparation of Bricks from Styrian Magnesite. — After sorting and classifying the magnesite is burned dead at white heat either in a shaft furnace provided with forced draft or in a rotary calciner. The raw material loses 50 per cent by weight; two parts of raw magnesite produce one of burned magnesia. The shaft furnace is lined in the hot zone with magnesia brick. The furnace works continuously; the burned material is drawn every six hours and again carefully sorted from the quartz or other impurities. The fritted magnesia is then tempered and ground with little water in a pan grinder, and formed into bricks in a hydraulic press, without the addition of any bond.

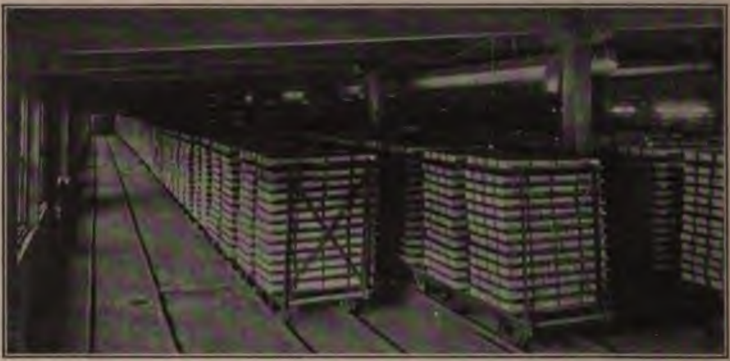

FIG. 38. — Drying in Tunnels by Means of Hot Air.

The bricks are then dried in tunnels or on a hot floor and burned at a temperature, which turns cone 29, in a downdraft kiln in America or in a Mendheim furnace in Europe. Thus, when the bricks are marketed their magnesia has been burned at least twice. In preparing material for crucibles and tuyeres three burnings in the Mendheim furnace are often necessary. The Veitsch bricks are dark brown. The English, made from the

Euboean magnesia, are light colored, higher in MgO and for some purposes especially useful.

Considerable care is taken in setting the dried magnesia brick in the kiln. Until burned they have little strength and a brick on edge may not be weighted with more than two bricks placed on it. Accordingly, in setting the bricks in the kiln a number of com-

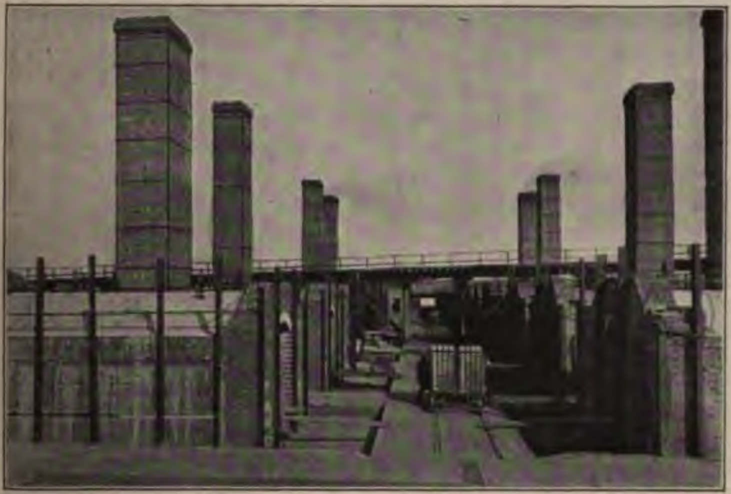

Fig. 39. — Magnesia Brick Kilns.

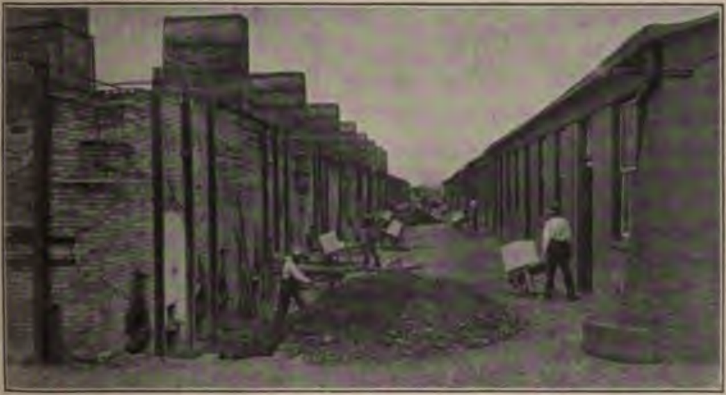

Fig. 40. — Magnesia Brick Kilns.

partments are made in this by setting up a framework of silica bricks. Into each of these compartments two layers of magnesia brick are placed so that the only weight on the lower brick is that of the upper. A kiln which holds 100,000 bricks will accommodate under these conditions only 40,000 magnesia, normal-sized bricks. Figs. 38, 39 and 40 show the drying tunnel and kilns of a modern magnesia brick plant.

Analyses of Magnesia Bricks

	1	2	3	4
	Per cent	Per cent	Per cent	Per cent
Magnesia	80.90	85.31	94.74	91.86
Alumina	1.60	9.05	2.67	1.95
Ferric oxide	6.80		Trace	Trace
Manganous oxide	.....	0.52	.....	.....
Lime	6.50	Trace	0.60	0.92
Silica or insoluble silicates	4.80	.....	1.53	4.68
Loss on ignition	.....	.....	0.24	0.22
	100.60	94.88	99.78	99.63

1. Silesian magnesia bricks. 2. Veitsch bricks. 3-4. English bricks. Kerl, p. 925.

Mortars. — Magnesia bricks are often laid in furnace walls, without mortar, skin to skin. The ordinary mortars used consist of 90 per cent fine magnesia and 10 per cent tar; they are laid hot and are of a thick sirupy consistency. Water may never be used, nor should bricks be packed in such a way that damp air may have access to them. To increase the refractoriness of fireproof ware fire-clay retorts or crucibles are sometimes dipped in magnesium chloride or other salt.

Magnesia is profitably used in basic Bessemer and open-hearth, in copper, reverberatory-converting and blast furnaces, in reverberatories and test furnaces used in metallurgy of antimony, lead, tin and silver, in malleable furnaces, in puddling furnaces and other vessels subjected to high temperatures and the attacks of basic slags.

Dolomite. — Dolomite is often used for basic linings and serves, less efficiently, the same general purposes as magnesite. Because it is less expensive, it serves a wide field of usefulness. The calcined rock or an artificial mixture of calcined dolomite and clay is ground fine with water, and the mouldable mass formed into bricks. After drying at a moderate temperature the bricks are burned until the clay and silica has combined chemically with the lime and magnesia.

By another method, similar to the manufacture of magnesia bricks, the dolomite is first burned dead, then crushed to pea size, mixed with tar and moulded in iron forms into bricks by means of hot stamps. Such bricks contract and crack at high temperatures. For this reason dolomite is used more generally as mass rather than in the form of bricks.

Bauxite. — The success of the higher-grade fire-clay bricks carrying large percentages of alumina paved the way for the application of materials of still greater alumina content. This led to the consideration of bauxite. Discovered originally by Berthier in an iron ore from Senegal, it was used first in France in the form of crucibles. It obtains its name from Colline des Baux in the south of France where considerable deposits are found, some of which are being exploited by the aluminum interests. In America the chief deposits are found in Alabama, Arkansas, South Carolina, Georgia and New Mexico.

Bauxite when pure has a light gray or white color; generally it is brown, yellow or red. Chemically it is an hydrated alumina bearing varying quantities of aluminum silicate and hydrated oxide of iron. Geologically it is regarded as a product of decomposition of basalt. The composition of various bauxites is given in the appended table.

	1	2	3	4	5	6	7	8	9
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
SiO_2	6.68	4.82	7.00	9.00	10.40	14.98	7.00	4.25	2.0
TiO_2		6.34							1.6
Al_2O_3	32.46	52.94	57.62	70.38	68.50	64.84	71.43	72.87	33.2
Fe_2O_3	38.94	2.58	4.24	5.12	3.44	5.38	0.57	13.49	48.8
CaO	Trace		1.74					0.78	
MgO	0.44	0.20	0.96						
K_2O	0.43	2.18	0.59						
Na_2O	0.21								
Gangue	0.73								5.8
P_2O_5	0.27								
Loss on ignition	19.90	30.94	26.99	15.50	17.66	14.80	16.80	8.50	8.6
	100.06	100.00	99.14	100.00	100.00	100.00	96.00	99.89	100.00

1. German.
2. Irish.
3. Origin unknown.
4-6. Department Herault, France.
7. From Montpellier.
8. Bright red Wocheinite (Bauxite).
9. From Calabria.

[*Handbuch der gesammten Thonwaarenindustrie*, Bruno Kerl, p. 915.]

Bricks are made with up to 80 per cent Al_2O_3. Bauxite contracts, cracks and softens considerably at high temperatures. It should be thoroughly burned before being made into bricks. The best bond is fire clay.

Preparation of Bauxite Bricks. — The bauxite is first washed and the purer material separated. This is burned and then crushed, mixed with one third to one sixth part of plastic fire clay, and then with the addition of water thoroughly worked and moulded. Attempts have been made to make the brick with lime instead of fire clay as a bond. The following analyses of bauxite bricks are from German and French factories.

	1	2	3	4
	Per cent	Per cent	Per cent	Per cent
SiO_2	26.93	41.00	24.77	33.70
TiO_2	4.14	.....	1.26	0.10
Al_2O_3	62.19	53.32	66.31	60.40
Fe_2O_3	4.44	2.64	5.31	5.40
CaO	0.17	0.57	0.34	.....
MgO	0.54	0.42	0.18	.....
K_2O	1.51	2.10	1.33	.....
P_2O_5	0.20	.....	0.26	.....
	100.12	100.05	99.76	99.60

1. Bricks from Forst near Aachen (Bischof, *Gesammelte Analysen*, p. 130).
2, 3, 4. From France. (*Thonin-Ztg.*, 1887, p. 177).
[*Handbuch der gesammten Thonwaarenindustrie*, Bruno Kerl, p. 916.]

These are by no means pure bauxite bricks, but the results of mixtures of fire clay and bauxite corresponding to the American "alusil" bricks.

The following is an analysis of a true bauxite brick made in America. SiO_2, 2 per cent, TiO_2, 5 per cent, Al_2O_3, 90.5 per cent, Fe_2O_3, 1.0 per cent and CaO, 1.5–2 per cent.

It is possible to increase somewhat the refractoriness of fire clays by the addition of finely ground bauxite; it must not be added to the mass as coarse grains, but in such a form that it may homogeneously blend with the clay. It is, therefore, important, in bringing the percentage of alumina in fire clay up to a certain desired amount, by such additions, that these be finely ground and well mixed or the resulting brick will possess simply the refractory coefficient of the original clay.

Bauxite has not come into more general use on acc
quality of shrinkage. Chemically it is very i

bonded easily into a brick of unusual strength but in all, except recent practice, the material has shrunk sufficiently to imperil the structure in which it was used.

A. J. Aubrey[*] claims that bauxite bricks and blocks made by the Laclede-Christy Company successfully stood some severe tests and argues the superiority of bauxite to magnesia in certain operations in the metallurgy of iron and lead, and to fire-clay brick in certain industrial furnaces such as rotary cement kilns.

These bricks are made in the following way. The crude bauxite is washed to remove some of the free silica and calcined, at cone 12, when the water of combination amounting to 30 per cent of the raw ore is expelled. The bauxite shrinks considerably, particularly between temperatures of cone 9 and cone 12. The washed and calcined Arkansas bauxite analyzes:

Mechanical water......	0.88 per cent
Silica.................	6.40 per cent
Iron sesquioxide.......	1.43 per cent
Alumina..............	87.30 per cent
Titanium oxide........	3.99 per cent

The calcined material may be bonded with fire clay, sodium silicate or lime and made into brick or tile, which, after burning at a high temperature in downdraft kilns, is said to be sufficiently strong to stand a crushing strength of 10,000 pounds per square inch. The calcination may be done in a rotary kiln. A brick 9 by 4½ by 2½ inches weighs 7.5 pounds. In a test made by the St. Louis Portland Cement Company a lining 6 inches thick in a 6-inch rotary kiln, 60 feet long, which burned pulverized coal, was removed after continuous run of eleven months. During this time 75,000 barrels of cement had passed over the lining and the average loss of the blocks was about 2½ inches.

The bauxite brick replaces a basic material in the iron and steel practice, but is not wholly proof against the action of bismuth or antimony or even lead slags. Pure alumina bricks and crucibles made by burning bauxite in the electric furnace, mixing the burned product with clay, moulding, drying and reburning, are more satisfactory. (See Alundum, p. 100.)

Should bauxite bricks become reasonably cheap, and methods of decreasing their physical weaknesses by burning at very high

[*] *Metallurgical Industry*, Vol. 4, p. 52.

temperature be employed, they would ultimately find a wide market.

The alusil bricks, placed on the market by Messrs. Harbison-Walker, approach bauxite in composition. These are high-alumina bricks, made from a batch containing fire clay to which nearly pure alumina, in the form of bauxite or other material, has been added, and have a special value when used in such furnaces as rotary kilns. Some of the alusil batches have as much as 70 per cent Al_2O_3. This same company now markets a useful high grade bauxite brick.

Alundum, or artificial emery, is made from bauxite in the electric furnace of the Norton Company at Niagara Falls, N. Y. It melts at 2300° C., and has a very low coefficient of expansion. It is inert chemically and is not, apparently, affected by slags made in the basic open-hearth process. Its high cost has not warranted its more general introduction up to the present time. Still, large quantities of aluminum crucibles, combustion tubes and boats, pyrometer tubes and muffles are employed with considerable success in high-temperature work. A unique production of the Norton Company is the alundum rapid-filter crucible, which retains the finest precipitates and allows the passage of the filtrate liquid. The precipitate may be washed, dried and burned, if necessary, in the alundum crucible, thus removing the use of paper.

Preparation of Alundum. — Bauxite is mined and sorted, the cleaner and purer material is selected and washed from dirt and dried at a temperature which drives off the uncombined water. The material is then forwarded to Niagara Falls, where it is calcined in a 60-foot rotary furnace to free it of the chemically combined water. It is then delivered to an electric furnace consisting of a crucible 4 feet in diameter and 5 feet high, having two carbon electrodes 4 by 12 inches in cross section. The calcined bauxite is fed into the arc in regular quantity. There it fuses and flows into the pot beneath. The pot holds an ingot which weighs 1½ to 2 tons. This is allowed to cool several days before it is broken. The alundum is then crushed to egg size and shipped to Worcester, where it is graded for the different purposes required and worked into marketable wares, by bonding with such materials as fire clay, sodium silicate (or perhaps even dextrin or tar), moulding, drying and burning at a high temperature.

Mr. L. E. Saunders has considerable praise for alundum bricks. These were tested in the Fitzgerald and Bennie laboratories in an electric single-phase two-arc steel furnace and proved capable of withstanding exceedingly high temperatures.* There are difficulties in using them at these temperatures in practical work. Basic vapors, such as those of lime and magnesia, attack the brick and form calcium and magnesium aluminates. The bricks break off in layers and the roof is destroyed. While they outlast silica brick, the cost of the alundum is at present prohibitive to their wide application.

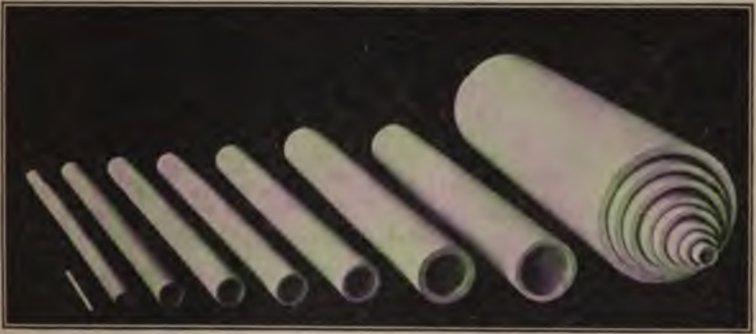

Fig. 41. — Alundum Tubes.

Chrome or Chromite. — Chromic oxide, Cr_2O_3, is not fusible at temperatures used in any industrial practice. It is the desirable constituent which makes chrome iron ore ($FeCr_2O_4$) valuable as a refractory to the furnace man. It raises the temperature of fusion of the purer kinds of this material sufficiently high to allow the application of their neutral salt in open-hearth steel furnaces. Accordingly, chromite is used for those furnace parts which demand a neutral refractory material without any reducing action such as the carbon refractories exert, and possessing some physical strength. Since, however, the purer kinds of ore contain at best only 50 per cent Cr_2O_3, with considerable alumina, ferrous oxide, and silica, it is clear that the brick which is made from such material will not contain more than 40 per cent Cr_2O_3 after allowance has been made for a quantity of admixed bonding material. Hence the softening point of chrome brick is lower than that of magnesia brick, and it is much less strong and resistant to high temperatures. It is, however, satisfactory in its resistance to the chemical action of slags, gases and dust. A 4½-inch line of chrome bricks is used as a "buffer" lining between the basic-magnesia and the fire-clay bricks when they join at the slag line. A layer of chrome is often placed between the magnesia bottom and the clay-brick foundation of a furnace. It is used to cover the "ports" of gas-fired furnaces, through which considerable dust, slag particles and gases of acid or neutral character may pass. It is employed widely about the tap holes of blast-furnace crucibles and settlers in the smelting of copper and nickel ores. The French antimony-oxide and ore-reducing hearths are lined with it. It resists the attacks of the oxides of antimony, lead and bismuth even better than magnesia. It is used, mixed with magnesia in the form of brick, for the bottom and sides of crucibles of the Laurium lead-blast furnaces. Fig. 42 shows the reserve store of The Harbison-Walker Co's. Chester plant.

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* *Metallurgical and Chemical Engineering*, March, 1912.

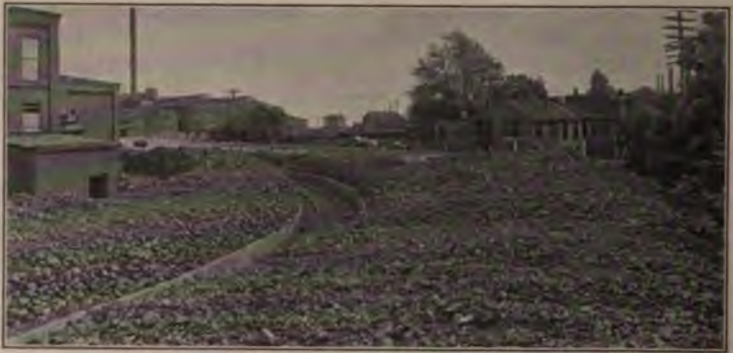

FIG. 42. — Chromite stored at Chester, Pa.

The Manufacture of Chrome Brick. — The most valuable deposits of chromite are found in Greece. Asia Minor, New Caledonia and Cuba contain deposits which are not at present drawn upon. The material is carefully picked and sorted before it is exported to America as crude ore. It is crushed in a Blake or gyratory crusher, and then mixed with fire clay or bauxite, or with bauxite and magnesia, or with magnesia alone; it is ground and tempered with a little water in a pan mill, moulded, dried and burned, as magnesia bricks are prepared.

Analyses of Magnesia-Chrome Brick.

	1	2
	Per cent	Per cent
SiO_2	5.23	9.20
Cr_2O_3	35.87	29.10
Fe_2O_3	15.26	16.14
Al_2O_3	31.28	21.36
CaO	0.91	0.01
MgO	11.43	24.10
	99.98	99.91

1. "Sprechsaal," 1893, p. 1075 (Seger).
2. "Magnesia and chromhaltiger stein" (Bischof, *Ges. analysen*, p. 143).
[*Handbuck der gesammten Thonwaarenindustrie*, Bruno Kerl, p. 929.]

Tar is sometimes mixed with it. Other binders used are burned lime, dolomite or magnesia. The ordinary kind of bricks consists of 90 parts chrome ore with 10 of bauxite or fire clay, or of 80 parts chrome ore, 20 parts magnesia, with often some bauxite or fire clay added.

Chromite bricks are unreliable in physical conduct when exposed to a temperature above 1500° C. They crumble and disintegrate. They become very soft and utterly disrupted when exposed to a temperature of 1800° C.* An unique property of chromite is its modulus of heat conductivity which does not change at high temperatures.

Properties of Chrome Bricks. — The use of chromite as a protective covering for furnace roofs, and as a coating on individual fire-clay and silica bricks has been developed. Messrs. McNight and Youngman have patented† the preparation of a brick which shall have for its body portion a refractory material which will not yield to pressure or lose form at high temperatures, and a surface portion which will likewise resist high temperatures and at the same time offer greater resistance to the chemical action of molten metals, slags and gases.

The chemically refractory surface which is added to the brick is not less than ¼ inch in thickness and is placed on that surface of the brick which will be exposed in the furnace. The main portion of the brick may be silica or fire clay such as is used in bricks of that nature; and this main body portion may be burned before the application of the refractory facing, or the facing may be applied to the unburned brick. The refractory facing is of chrome ore, burned magnesite, aluminous clays or aluminous products. A suitable binding medium of relatively low fusing point is placed between the body portion and the refractory facing so that in burning the completed brick, the facing will be fused to the main body. In cases where magnesite is used in connection with a silica-brick portion, the fusible binder may be omitted, as a fusion can be obtained directly between the magnesite and silica at suitably high temperatures.

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* Private communication from Chemical and Metallurgical Laboratories, University of Wisconsin.

† U. S. Patent, No. 1,016,350,

It is claimed that chromite bricks soften at the temperatures of the open-hearth furnaces; some American practice might disprove, however, that the furnace walls were weakened in any way, or the value of the hearth bottom impaired by the regular insertion of a layer of chrome brick between the basic and fire clay or silicious materials. An American chrome brick analyzed as follows:

SiO_2	0.05 per cent	Cr_2O_3	39.68 per cent
Fe_2O_3	6.02 " "	Al_2O_3	18.88 " "
FeO	18.10 " "	CaO	1.23 " "
MnO	0.35 " "	MgO	16.00 " "

A brick of this character was tested for three and one-half hours at a temperature ranging from 2958° to 3011° F. The expansion was 0.70 inch per linear foot. The permanent elongation was 0.052 inch per 9 inches. In this test the brick cracked badly and crumbled on removing from the furnace.

Charcoal Bricks. — The refractory qualities of such a neutral material as carbon have been recognized for many years. It withstands sudden changes in temperature, resists the effect of high temperature and resists the chemical action of slags, ashes and gases. Coke braize has long been valued as a foundation under the hearths of reverberatory metallurgical furnaces and the hearth itself is often made of a mixture of fine coke and fire clay. Particular advantages of the charcoal bricks are their poor conductivity of heat, the extremely small expansion at high temperatures and their resistance to both acid and basic slags under conditions in which these contain no oxides reducible at the temperature employed. At high temperatures the carbon of an arc will reduce such oxides as magnesia. Charcoal bricks may not be used at high temperatures when they are exposed to the air or other oxidizing influences unless provision be made to cool them. They are in this respect not neutral. Carbon becomes plastic at temperatures as high as 2500° C. Watts and Mendenhall were able to bend American charcoal bars at 1800° C. and a stick of graphite at 2150° C.[*] Carbon does not melt; it boils at 3700° C. and volatilizes considerably below this temperature.

The Manufacture of Carbon Bricks. — The coke selected for the manufacture of the carbon bricks should have a low content of ash. It is dried, ground and sifted and homogeneously mixed with 20 per cent of tar. If possible, heat is applied during the mixing. The plastic mass is now stamped into wooden forms and then dried on hot floors. The subsequent burning must be done in such a way that no oxidation or burning of the coke is possible. In Europe chamber furnaces of the Mendheim type are used. In these special muffles are built in which the coke bricks are placed. Interstices between the bricks are filled with ground coke to prevent combustion of the bricks. During the process of burning the tar also cokes and makes a homogeneous mass with the original coke of the brick.

The most satisfactory mortar to use with the coke bricks is a mixture of 2 parts coke dust and 1 part clay or of 4 parts coke and 1 part of clay. Graphite bricks are made in all sizes; they are denser, heavier and finer ground than the old type of charcoal bricks. These are made by the Acheson Graphite Company, at Niagara Falls. This same firm prepares the carbon silicon compound, carborundum (C Si), which makes an excellent fireproof paint when applied to furnace roofs and walls. Another such compound is siloxicon. Graphite is more often used in the manufacture of crucibles. Varying quantities up to 50 per cent of clay are mixed with the graphite. These are made in all sizes and in many shapes. Plumbago is used as a fireproof and acid-proof coating for iron and steel. It is also used for dusting in the sand moulds used in making fine castings. All forms of carbon oxidize readily, graphite least readily of all. They should not be used at a high temperature or in contact with oxide slags.

In Europe the Morgan and in America the Joseph Dixon crucibles have won enviable distinction. For further details on these refer to Chapter XII.

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[*] *Annalen der Physik* Band 35, 1911.

Lime, cement, bone ash and marl are used in furnace bottom as mass, particularly in lead refining and in crucibles. Further information is given under the chapters on crucibles and furnaces used in general metallurgical industry.

Other Refractory Insulating Materials and Paints. — Asbestos, a double silicate of lime and magnesia, has many useful applications in the making of crucibles where it bonds and holds the ground mass together, as a fireproof mortar in admixture with tar, and as a fire-resisting paint when mixed with water glass. It is also used as a nonconducting packing about steam and water pipes and is used widely in the form of sheets in laboratories on sand and water baths and over direct flames or hot plates to protect and distribute heat to the glassware or dishes resting on it. Asbestos thread sacks are used for the filtering of fume from metallurgical furnaces. The patent filters of Fiechter are used in salt, flour and other mills. The use of the material is growing, as methods of working it into useful textiles and forms in which it readily finds application are developing. Care must be observed in using asbestos alone, as it quickly disintegrates at high temperatures. For further information see the chapter on refractory mortars and cements.

Concrete as a refractory material is most unsatisfactory. It cracks under the actions of hot neutral furnace gases at 120° C., and sulphurous and sulphuric acids in flue gases soon corrode it with especial rapidity if the gases are moist or if outside moisture can penetrate to the flue.

As a material for tests and cupelling furnaces it is, on the whole, unreliable. Some hearths stand fairly well and others break up immediately. Floors of metallurgical and chemical buildings should not be made of concrete, since metallic salts seep into it and, crystallizing in narrow confines, disrupt the floor. It is for the same reason unsuited for reservoirs holding acid liquors.

THE CARBON-SILICON REFRACTORIES

Carborundum — Crystolon, Siloxicon and Carborundum Fire Sand. — Two analyses of carborundum are as follows:

(1) $SiC = 87$ per cent, $SiO_2 = 12$ per cent, $Fe_2O_3 = 4$ per cent.

(2) $SiC = 75$ per cent, $SiO_2 = 20$ per cent, $Al_2O_3 = 3$, $Fe_2O_3 = 1$, $CaO\ MgO = 1$.

It is produced in the electric furnace by the heating together of sand, sawdust and coal at a high temperature. It is a carbide of silicon and is crystalline in nature. It may be ground and mixed with tar, glue, sodium silicate and used as a protective paint or it may be mixed with about 15 per cent of fire clay and burned into brick. It withstands temperatures up to 2220° C. when it commences to dissociate but at 1470° C. its silicon content commences to oxidize and the material suffers in refractoriness. It is extremely refractory to most basic and acid gases, dust and clays. The conductivity of carborundum is 5 times that of clay bricks. Its density is 3.02 to 2.83: the volume density is 1.96. The porosity is about the same as fire brick, .30; its permeability only one-tenth, namely, 0.0053 cm^3 second.

While carborundum is the name given to the crystalline silicon carboride, and carborundum fire sand, or silicon to the amorphous impure silicocarbide made by the Carborundum Company, the Norton Company classify their two products under the general term crystolon, and differentiate crystalline and amorphous. The use of these materials was first patented by Talbot.* He gave preference to the amorphous carbide because it was adaptable and less expensive for general metallurgical purposes. He claimed, in his patent, the use of carbide of silicon (bonded with tar or other substance) as a refractory lining for furnaces and metallurgical structures.

The carborundum fire sand or amorphous crystolon is a product of the first stage in the formation of crystalline silicon carbide, and generally consists of a more or less heterogeneous green colored mass of silicon carbides (amorphous and crystalline) with certain silicocarbides $Si_xC_xO_y$. In heating a mixture of sand and carbon slowly to the point where the carbon and silicon react and combine, the outer part of the charge will be green and contain some unconverted mixture along with siloxicons. Near the source of heat the substance changes from amorphous silicon carbide to the real silicon carbide or carborundum. The carborundum finds wide use as an abrasive, particularly in the form of grinding and polishing wheels; the amorphous fire sand is used in the form of brick or of mass for lining and coating metallurgical furnaces.

From a bulletin entitled "Carborundum Refractories" and issued by the Carborundum Company, of Niagara Falls, N. Y., the following information on carborundum fire sand is abstracted.

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* U. S. Patent, No. 6282688.

Chemically, carborundum fire sand consists of several silico-carbides of compositions ranging from $Si_2C_2O_2$ to Si_6C_6O, representing the partial reduction of silica by carbon at the intense heat of the electric furnace. It is furnished in the form of finely ground sand and is mixed, before applying, with a binding material such as silicate of soda or fire clay to give it proper cohesion when brought up to heat. A silicate of soda of 52° Baumé is best adapted for this purpose; it must be diluted with a certain quantity of water before being added to the fire sand. When clays are used, a crude New Jersey fire clay or one of equal purity should be taken. Kaolin may also be used with good results. Prepared fire clay, such as is furnished for laying up fire brick, is generally mixed with ground calcined clay or powdered fire brick, and is not suitable for the purpose.

In estimating the amount of material required for a lining of given dimensions, the weight of the carborundum fire-sand mixture may be computed as 85 pounds per cubic foot.

Lining of Crucible Brass Furnaces. — For linings of crucible brass furnaces a mixture is used consisting of 70 per cent carborundum fire sand, 15 per cent ground fire clay, 8 per cent silicate of soda of 52° Baumé and 7 per cent water.

The silicate of soda is first added to the water and thoroughly dissolved. This solution is then mixed with clay and fire sand until the material acquires the consistency of moulding sand. The constituents when thoroughly incorporated form a plastic mixture which is easily moulded and has sufficient cohesion when tamped into place to retain its shape until fired. A sheet-iron form is provided of the same diameter as the interior of the furnace, consisting of a sheet of iron bent in cylindrical form, so that after use it can be sprung in and easily withdrawn. The center may also be constructed of wood and in such case should be well greased so that it can be drawn without the lining adhering to it.

The mixture is rammed up solidly between the center and the outside shell of the furnace, after which the center may be at once removed and the lining dried out with a slow wood fire. It can then be immediately put into service. In cold weather it is well to warm all the materials before mixing.

It is the practice in some foundries to provide channels or vents to assist in drying out the lining. This is done by placing 4 or 5 wooden strips, about 2 inches by 1 inch, spaced equally around the furnace inside and against the shell. These are withdrawn after tapping in lining. This same mixture is used for lining ladles for brass, copper or iron melting.

Linings of Tilting and Rotary Oil-burning Furnaces. — For tilting and rotary brass furnaces, in which the linings are subjected to the severest possible conditions, a mixture of 86 per cent carborundum fire sand, 7 per cent silicate of soda at 52° Baumé and 7 per cent water is recommended. In many cases it is found advantageous to replace about 15 per cent of the fire sand with an equivalent amount of kaolin.

This mixture is thoroughly incorporated and tamped between the shell of the furnace and a strong center provided for the purpose. When completed the center is carefully removed and the lining dried out at once with a slow wood fire. It is then gradually brought up to heat by means of the oil flame and can at once be put into service.

Many users of this style of furnace have found it practicable to throw in a small quantity of broken glass when first heating the lining. This glass, when melted, can be evenly distributed over the surface of the lining by tilting the furnace, and the interior thus acquires a smoother glazed surface which adds to the durability of the lining.

Patches can be easily made in places where the lining becomes broken or worn. It is best to cut out the broken parts, undercutting the old lining, in order that the new portion may be keyed into the old lining. For the purpose of repairs the same mixture is used as when putting in a new lining.

Repair of Fire-brick Linings. — A mixture consisting of equal parts of carborundum fire sand and fire clay or kaolin is extensively used for patching holes or broken parts of fire-brick linings and for filling open joints in furnace walls. It is used to good advantage in ordinary crucible furnaces for brass and steel, also in copper reverberatory furnaces for keeping the side walls in repair. By its careful use it is possible to double the life of any fire-brick lining. The mixture is largely used in repairing the Schwartz downdraft furnace, and also as a wash applied daily after the melting. Another efficient mixture for this purpose is the one recommended for crucible brass-furnace linings given above.

A mixture of equal parts of fire sand and fire clay is used successfully in repairing the brick linings of Tropenas converters, which are subjected to extreme corrosion by the flame.

Carborundum Furnace Paint. — Carborundum fire sand may be made up in the form of a paint or furnace wash by mixing 65 per cent carborundum fire sand with 20 per cent ground fine clay and 15 per cent silicate of soda of 52° Baumé and adding sufficient water to bring it to the consistency of a thick paint, which is applied to the surface of the lining with a broom or stiff brush. Two or three applications gave a proper coating. This makes an excellent protective coating for furnaces subjected to intense flame action and high temperature. It is preferably applied to new brickwork, as it does not adhere so efficiently after the linings have become glazed over or covered with slag.

Special applications of carborundum paint are used in arch and bridge walls of boiler furnaces which are subjected to severe flame action, in potters' kilns, welding furnaces and malleable iron furnaces. It is of great value in oil furnaces in protecting the bricks from the well-known pitting and eating action of the high-pressure oil flame. Carborundum paint is used with good results as a cupola wash in protecting the melting zone of foundry cupolas.

Carborundum Mortar is made from a mixture of equal parts of carborundum fire sand and fire clay. It is used in laying up fire brick, in patching open joints and holes in brickwork and in general repairs. The life of a fire-brick structure is generally limited by the life of the joints. A mortar of carborundum fire sand is found to effectively stop the slagging and corroding at the joints.

Carborundum fire bricks are furnished in the regular size, 9 by 4½ by 2½ inches, and also in many of the special arch and key shapes. Many special shapes and forms are also made according to specifications and drawings. Carborundum bricks have made economy in oil furnace work of all descriptions, in connection with the melting of crucible steel in forging and welding furnaces, in electric furnaces and in brass furnaces. They are, moreover, the only bricks which will stand the intense heat generated in furnaces using powdered coal fuel.*

The Metal Refractories, Iron, Copper, Nickel, Platinum and Lead. — Iron is most refractory in the cast or pig form. As such it is used in lead smelting in the shape of kettles in which base bullion is desilverized. The slag of zinc and lead oxide, which is formed on the top of the bath during the process, does not attack the metal. In fact the life of the kettle depends mostly on its capacity to stand alternate heating and cooling. It generally cracks first at the bottom, where the greatest heat and weight is felt. For this reason the kettles should be cast with the bottoms down. Cast-iron and wrought-iron pans are used in making red lead. This is a dry process, the oxides do not fuse and the pans wear well.

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* From *Metallurgical and Chemical Engineering*, Vol. 9, No. 11, p. 614.

Cast iron has not proved successful in replacing marl, cement and magnesite in cupelling hearths. It is equally unsatisfactory as a ladle for holding matte and metal in copper smelteries. In lead blast furnaces the slag spout may be made of iron. All spouts holding matte should be made of other material such as water-cooled bronze or copper.

Cast iron finds considerable application in the chemical industry in the form of evaporating pans and crucibles.

Steel flues have been used for many years in Germany and America. The water-cooled iron flues last fairly well, but the ellipse-shaped flues of some of the western works have not proved, on the whole, as economical as bricks. One advantage they possess lies in the cooling effect they have on the gases and the consequent comparatively rapid condensation of fume. Any steel tie bars, rods, stays or beams which are exposed to the action of hot air and gases should be covered with water-glass and asbestos, graphite, plumbago, carborundum or other fire- and air-resisting paint.

Copper is an exceedingly useful material in smelteries. The tuyeres in iron-blast furnaces are often made of bronze. Most spouts brought in contact with matte or metallic copper should themselves be made either of copper or a copper alloy and be water cooled, or they should have an attached water-cooled lip of copper. Ladles and transfer cars are lined with copper or bronze. Copper is attacked much less readily than iron by both molten sulphides and oxides.

Iron oxidizes readily, particularly when hot, and starts chemical reactions when holding molten slags and mattes which soon destroy it. Nickel, platinum and gold are better materials for the manufacture of small laboratory crucibles. Nickel stands a temperature of 1400° C., platinum and gold much higher. Platinum kettles are used in heating sulphuric acid in the process of concentrating and freeing it of arsenic; it would be much more widely used were it not exceedingly expensive.

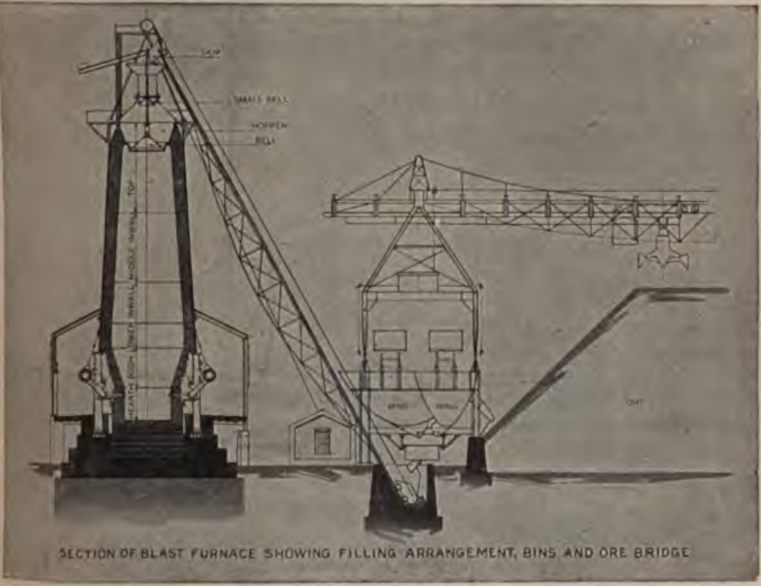
It is being replaced, to some extent, by electric quartz glass made by the Thermal Syndicate of Wallsend-on-Tyne.

Lead, while not refractory to heat influences, finds a wide range of usefulness in chemical and metallurgical plants, in the form of sheet-lead lining for protecting the interior of iron and brass pipes from the attacks of acid liquors, and for the exterior protection of fans working in acid gases. Large quantities of the metal are still used for such purposes as chambers in sulphuric-acid plants, and for lining electrolytic and leaching tanks. In these the lead contains some antimony, which makes it harder and more resistant to corrosion. Even one per cent of antimony serves to make the lead more resistant to acid attacks.

CHAPTER VI

THE USE OF REFRACTORY MATERIALS IN THE METALLURGY OF IRON AND STEEL

THIS industry, more than any other, demands large quantities of varying character and qualities for its different furnaces and operations. The iron blast furnace with its accessory plant of hot stoves, the steel plant with converters, cupolas and reverberatory furnaces, the refining, casting and milling departments, the coke ovens, gas producers and special alloy crucibles and furnaces, all need refractory material which must be carefully selected and sensibly used. The modern blast furnace, a vessel 100 feet high from hearth to platform level, tapers from the upper bosh line where the furnace is generally 22 feet internal diameter



SECTION OF BLAST FURNACE SHOWING FILLING ARRANGEMENT, BINS AND ORE BRIDGE

FIG. 43. — Blast Furnace.

to the top of stock line where it is about 15 feet in diam and down to the top of the crucible which has a diameter of ab 14 feet, 6 inches, clear. These dimensions vary slightly in dif

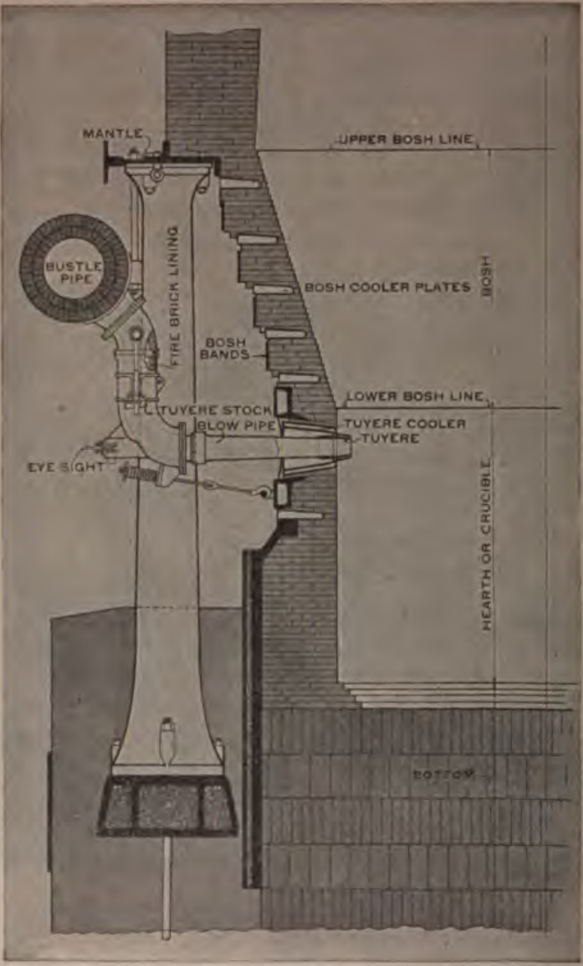


FIG. 44. — Crucible and Bosh of Iron Blast Furnace.

ent works but the relation of the diameters of the three sect of well, bosh, and shaft remain very similar. These three sect are termed, respectively, the hearth or crucible, the bosh and inwalls, which is the name given to the shaft of the furnace the fact that the wall is held inside a riveted steel shell. The inwalls of the shaft are again divided into the lower inwall extending 25 feet above the bosh, the middle inwall extending the next 20 to 25 feet above the upper inwall or top.

The slag is generally silicious, a bisilicate, as a rule, containing about equal parts of acid (silica and alumina) and base (lime and magnesia). It would, therefore, tend to corrode a basic lining, if such were economical and feasible. It has little or no effect on an acid lining, yet we do not use a straight silica brick but get better results from the very much stronger fire-clay brick, which contains about 40 per cent alumina and 55 per cent silica and acts as an acid when in contact with supersilicious slags.

The whole thickness of wall of the well or crucible is made of high-grade fire brick. The brickwork, from 27 to 36 inches thick, is surrounded by a steel jacket either of heavy riveted plate or still heavier castings of steel or iron built round the whole well in segments. The outside of the plate jacket is sometimes cooled by a water spray; the castings are rarely cooled by means of a trough of water about the exterior. Sometimes pipes for cooling water are cast in the jacket. The bottom of the crucible is made of fire-clay bricks or blocks which are specially manufactured. Although the bottom has an enormous weight of slag and metals to carry, the whole weight of the contents of the furnace does not rest on it. The upward pressure of the blast of from 20 to 30 pounds to the square inch relieves the bottom and the bosh which also supports some of the weight of the "burden." The thickness of the bottom depends on the size of the furnace. A depth of at least 5 feet is demanded in small furnaces, usually two or three times this thickness in large modern furnaces. The bottom blocks, which are generally larger than the ordinary brick, measure 18 (height) by 8 by 12 inches or 18 by 9 by 4½ inches. They are set so as to break any possible line of joints. This is shown clearly in Fig. 45. These blocks are made under heavy pressure and are truer in shape and form than the ordinary bricks. They require less fire-clay mortar since they are set closely and the whole set fits tightly inside the jacket. If the joints are not tight or the lines of joints are not broken so as to stagger them in the vertical plane, the molten metal will seep through, at first in small, but ultimately in large, quantities. Beneath this thick bottom of fire-clay blocks is laid a deep foundation of inferior fire brick and concrete.

Chemical and Physical Analysis of Normal-sized Hearth-wall Bricks, 9 by 4½ by 2 Inches.

Loss on ignition.	Chemical analysis, percentages.						Crushing strength, in pounds per square inch.		
	SiO_2.	Fe_2O_3.	Al_2O_3.	CaO.	MgO.	K_2O.	Side.	Edge.	End.
0.07	50.57	3.87	42.73	0.25	0.34	2.17	5153	2113	1342

True sp. gr., 2.33.
Porosity, per cent volume, 14.92.
Abrasion, 0.180 cubic inches.
Average elongation per 9 inches, 0.42 inch.
Tested at temperature 2925–2983° F.

Specific gravity, by volume, 1.98.
Absorption, per cent weight, 7.53.
Average permanent contraction per 9 inches was 0.042 inch when cooled.

The tapping hole through which the iron is drawn from the well is 18 inches or 2 feet above the bottom and faces the pig bed when the iron is chilled in metal or sand moulds. It is of square section, each side being from 2 to 3 inches in length. It is closed, when metal is not being tapped, with a clay cone or ball which is sufficiently plastic to be moulded by hand. This burns into place and becomes as firm as the wall.

The slag hole or cinder notch is placed above the tap hole and distant from it ¼ of the circumference of the well. The notch marks the top of the possible iron content in the well, and the height above the bottom is planned so that the desired quantity of metal may accumulate before every tap. Through the cinder notch, slag alone flows. This slag, when running (at a temperature of 1580° C. = 2876° F.) from the furnace, corrodes by physical and chemical action any material which is allowed to become hot. This applies to the fire brick which would gradually be eaten out and an unmanageably large notch or hole would be produced. There is, accordingly, a hole left in the wall into which the actual notch cooler fits. This is made of a series of hollow tapered-bronze, copper or cast-iron coolers, in the shape of a frustum of a cone through which water circulates. The outer and largest part is termed the cooler, the next smaller, the intermediate cooler, and the innermost, reducing the diameter to 2 inches or 2½ inches, is called the monkey. This penetrates a short distance into the furnace beyond the wall of the crucible. The monkey is stopped by a tapered iron plug attached to a long iron bar when the slag stream or flush is shut off. Water circulates throughout by means of inlet and outlet pipes. If the iron rose to the level of these coolers, it would cut them at once and then, meeting the cold water, would explode. The molten iron does not attack the brickwork of the well; the liquid, hot slag has no effect on the water-cooled bronze, copper or iron notch coolers.

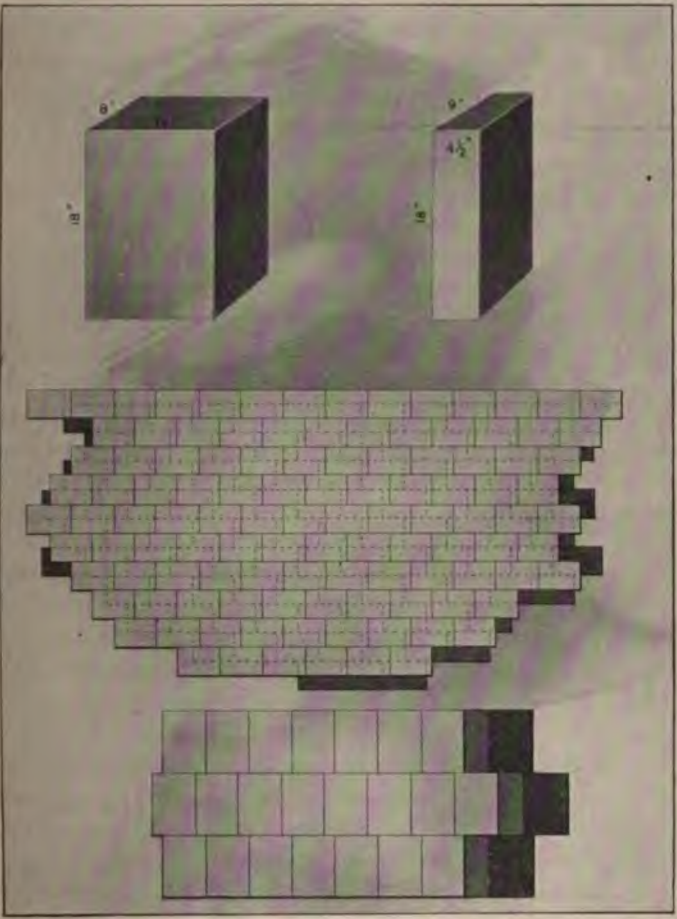


Fig. 45. — Bottom Blocks in Blast Furnace, showing Method of Breaking Joints.

Just as the position of the cinder notch limits the rise in the well of the metal pig iron, so the tuyeres or the apertures, through which the blast is admitted, govern the height to which the slag may rise. There are from 10 to 16 of these situated from 2½ to 4 feet above the level of the cinder notch. These are similar to the cinder notches in that they consist of an outer cooling ring fitting into a conical hole left in the walls, but cut off flush with the interior and exterior of the furnace walls. In this outer cooling ring is fitted the tuyere itself which projects into the furnace somewhat beyond the plane of the inside of the lining.

The tuyere is a small, hollow, bronze or phosphor-bronze casting which extends from a few inches outside the interior face of the lining to about 9 inches into the furnace, beyond the wall. The water generally circulates from the bottom entrance pipe to the top exit pipe. The diameter of the tuyere opening varies from 3½ inches to 7 inches. The air-blast main surrounding the furnace is called the bustle pipe. It is connected to the tuyere by the tuyere stock, which is made in two sections of cast iron and is lined with 2 inches or 3 inches of fire-clay brick. It is flanged and bolted to a flanged arm of the bustle pipe and attached at the bottom to the furnace bands by a spring. A second connection, called the blowpipe, which rests against the inner tuyere, is held in the stock in a ball-and-socket ground joint. At the back of the tuyere stock and in direct line with the blowpipe and tuyere is the eye sight, an opening closed by a piece of glass or mica.

The bustle pipe is a cylindrical, sheet steel pipe, lined with from 9 to 12 inches of fire-clay brick. It is suspended by straps or brackets from the furnace columns at a height of 10 to 15 feet above the floor. The reason for lining the bustle pipe and tuyere stock lies in the fact that hot-air blast is used. The main carrying this from the stoves must also be lined to a thickness of 9 to 12 inches. This lining must be hard and tough to resist the abrasive action of the blast laden with dust from the stoves. It has to withstand variation in temperature and may not, therefore, be too dense and rigid. A fire-clay brick is made in shape and composition to suit these bustle-pipe linings.

The bosh or middle section of the furnace extends from the top of the hearth to the lowest part of the inwall or shaft proper. It is made in one of two ways. The first form is shown in Fig. 44,* with the brickwork stepping up from the smaller circum-

* "A Study of the Blast Furnace," by Harbison-Walker Refractories Co., p. 17.

ference of the hearth area to the larger section at the junction with the inwall. Every step of about four bricks (on edge) is girdled with an iron band; between the bands are bosh-cooler plates through which water circulates. These are of bronze or copper, and may be baffled or open. In the former type the water is led to the back or nose and returns past the baffles. The plates are generally as long as the walls are thick. Their object is to cool the brickwork of the bosh, which is the hot zone of fusion of the furnace. The walls of the bosh are 27 inches thick and made of fire-clay brick. In a second method of construction the walls are from 9 inches to 13½ inches thick and girdled by a continuous steel shell which is cooled by water running from an upper trough, down the plate, into another trough and so on down to the bottom trough which conducts away the now hot water. The bosh brick may be made from the same refractory mass used in making hearth or crucible brick.

The stack or inwall of the furnace rests on a mantle of heavy steel plates and angles carried on a number of hollow cast-iron pillars embedded in a firm foundation of concrete. This mantle carries the weight of the shell and the inwall; in fact, it supports the whole furnace exclusive of the hearth, the bosh and the contained charge or burden. Thus the bosh and hearth may be removed independently of the rest.

The inwall of fire brick inside a steel shell extends from the mantle to the bell and hopper charging device at the top. It is true that for a short distance below the bell the walls may be vertical. At the point where they commence to assume the shape of a cone, the diameter of the furnace section is about 15 feet. This gradually increases in diameter until it reaches 22 feet clear at the top of the bosh. The cold charge fed at the top of the shaft gradually expands under heat until it is on the point of fusion at the top of the bosh, when it contracts in its gradual change from solid to liquid state during its passage through the boshed section. The lining of the lowest part of the inwall may be as thick as 5 feet; it generally tapers from here toward the top where it is from 27 to 41 inches thick.

In more recent years it has been found conducive to the maintenance of the inwall to insert cooler plates. They are placed farther apart than in the bosh. Jackets or plates for cooling must increase the life of the masonry. [illegible] basic bricks are not attacked by the oxides, slags and salts, formed in a blast furnace until they are heated. Cold lining suffers less from the physical wear and tear of the descending charge grinding along the walls. The top of the furnace is closed by a double bell and hopper. The gas escapes by 1, 2, 3 or 4 openings at the top of the furnace. From these openings in the furnace walls flues or pipes lined with fire-clay bricks lead the gases downwards to the dust catcher whence they go to the stoves. Here the gases give up their sensible heat, which is that which would register on the scale of a thermometer or of a pyrometer, and part of their latent heat, due to the combustion of some part of the gases. After leaving the stoves they are burned under boilers or in gas engines.

The manufacture of bricks for the inwall or shaft is a favorite specialty with refractories companies. The quantity needed is larger than in almost any other department of iron and steel manufacturing. The properties of two representative brands are described in the following result of chemical and physical tests.*

Kind.	Loss on ignition.	SiO_2.	Fe_2O_3.	Al_2O_3.	CaO.	MgO.	K_2O.
Inwall (1) 9 in. × 4½ in. 2½ in.	0.07	54.44	2.53	40.01	0.18	0.53	2.24
Inwall (2) same size	0.07	56.07	3.32	39.00	0.12	0.18	1.30

Crushing strength, pounds per square inch.			Specific gravity, true of volume.		Porosity, per cent volume.	Absorption, per cent weight.
Side.	Edge.	End.				
5098	3840	2693	2.34	2.03	12.93	6.36
5248	2170	2710	2.43	2.10	13.30	6.32

	Abrasion.	Expansion in inches per linear foot.	Average permanent elongation per 9 inches.	
	0.120 cu. in.	0.042	−.021	
	0.072 cu. in.	0.064	....	

(1). Tested 2½ hours at temperatures, Average 3016° F.
Maximum 3157° F.
(2). Tested at maximum temp. of 3000° F.

The bricks used in lining the downtake or downcomer, which leads the gases from the furnace top to the dust catcher, are of similar quality. The shape and size depends on the size of the downtake. As a rule it has a 9-inch or 18½-inch fire-clay brick lining.

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* Private communication.

The dust catcher is a large brick-lined vertical steel cylinder, from 15 to 30 feet in diameter usually with a dome or conical top, and with an inverted conical bottom. This has an opening through which the accumulated dust may be discharged. The dust is deposited on account of the larger volume of the dust catcher and the consequent decreased velocity of the gases coming from the narrower downtakes or downcomer. From the dust catcher the gas is piped to the hot-blast stoves through the gas mains. The lining of the gas mains is made half a brick thick. In the dust catcher the lining is generally 9 inches. In the downcomer and dust-catcher gas mains the lining is exposed to only fairly high temperature, but must resist the abrasive action of the furnace gases rushing through and laden with dust from the ore, the fuel, and the limestone and fluxes. Accordingly the brick must be dense and tough and at the same time resistant to considerable heat. They are made in standard sizes of suitable fire clay for flues with diameters of 3, 4 and 5 feet. The standard sizes are:

(1) For flues of 3 feet diameter 13½ by 9 by 3½ by 2¼ inches; also 9 by 9 by 3½ by 2¼ inches.

(2) For flues of 4 feet, 13½ by 9 by 3½ by $2\frac{17}{32}$ inches; also 9 by 9 by 3½ by $2\frac{17}{32}$ inches.

(3) For flues of 5 feet, 13½ by 9 by 3½ by $2\frac{11}{16}$ inches; also 9 by 9 by 3½ by $2\frac{11}{16}$ inches.

(4) For enlarging these circles, 13½ by 9 by 3½ inches and 9 by 9 by 3½ inches.

The downtake pipe which leads the gases away from the furnace becomes very hot only when the furnace is running abnormally; under ordinary conditions the temperature of the gases leaving the furnace is from 500° to 700° F. The temperature at the tuyeres is 2732° F., and the blasts of air entering through the tuyeres has been prepared to effect this result, by being heated to about 1100° F. in hot stoves, into which it is driven by the blowing engine.

The hot stove is a large chamber lined with fire-clay bricks and holding a system of checkers or brick regenerative chambers in which the heat from the out [illegible] stored to be later transmitted to the inblowing blast. There are four of these hot stoves to every furnace; three are receiving heat from the downcoming gases from the furnace, while one is transmitting its

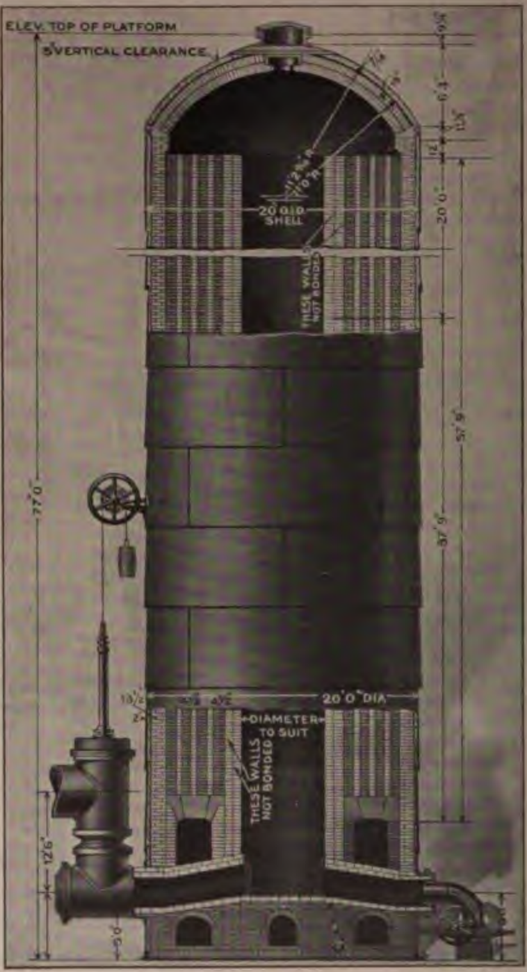

Fig. 46. — Hot Blast Stove. (Julian Kennedy Type.)

received and stored heat to the inblowing air to the furnace. In order to distinguish between the two main pipe lines, the downcoming from the furnace and the ingoing to the furnace, the former is called the "cold side" and the latter the "hot side."

The hot side must be, just as the cold side, provided with a lining of fire-clay brick.*

It is of the greatest importance to the satisfactory and least costly maintenance of a blast-furnace plant that the lining of the hot-blast stoves be selected from suitable fire-clay bricks. These bricks should be well bonded, heat-absorbing and non-vitrifying at temperatures up to 1500° F. They should be sufficiently tenacious to resist the abrasion and friction of dust travelling in the gases. Their shape should combine strength with the greatest possible surface for the absorption and remission of heat.

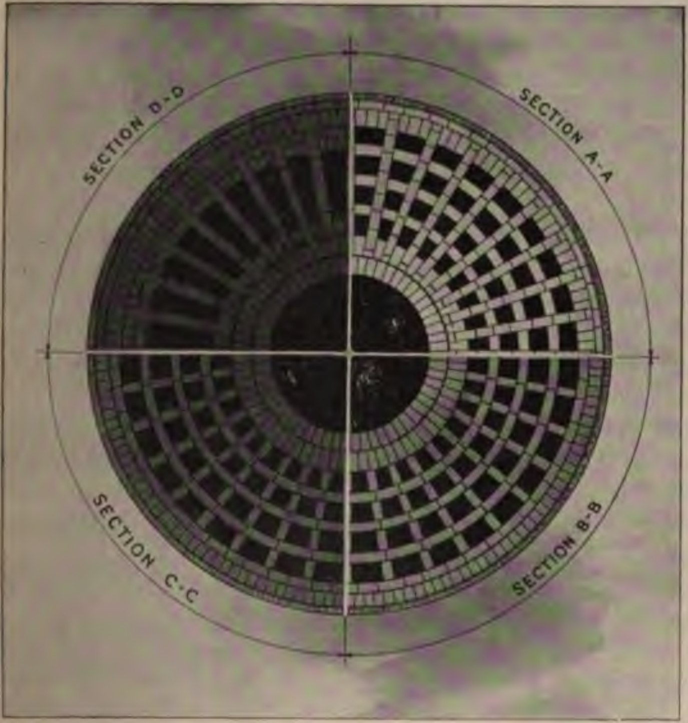

FIG. 47. — Sections through Hot Blast Stone. (Julian Kennedy Type.)

They must be strong because the stoves are built as high as 130 feet, and the lower bricks or shapes must bear a heavy burden; they must absorb, hold and remit heat, because the whole function of the stove is to abstract the heat from the gases passing through them from the blast furnace and transfer it, when the stove has been thoroughly heated, to the cold air blast in its passage from the blowing engine to the furnace.

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* "Study of the Blast Furnace" by Harbison-Walker Refractories Co., p. 13.

The lining of a blast furnace is liable to destruction from a multitude of causes, and the most refractory fire bricks will not be fool proof against mismanagement of the furnace. The longest lived furnaces are those which are most carefully warmed, blown in, and charged under the continuously watchful eyes of a wise superintendent. When a furnace, new or relined, is to be blown in, the first care is to dry the brickwork thoroughly. Even though the fire-clay bricks for the lining are laid with the thinnest possible joints, there is always some moisture in the "grouting" or "slurry" of fire clay, and there is quite a large quantity of this used for "pointing" and in the interstices. At first a light fire of wood or from gas burners is made on the hearth and kept going with increasing intensity for two weeks. This work should not be hurried as the subsequent length of life of the lining of the whole furnace depends on it.

The character of the slag formed has a great effect on the life of the lining. It must be so composed that it is neither too viscid nor too fluid at the normal temperature produced in the furnace when running under fair conditions of reduction and fusion. A liquid slag corrodes the lining very quickly. The regular slag, a bisilicate or sesquisilicate of lime and magnesia slag, gradually attacks fire-clay bricks. Fortunately, however, the lining is very soon protected by a deposition of carbon, at a temperature of 400° C., the CO of the gas, rising in the furnace and in the presence of oxides of iron, etc., deposits C.

$$2\,CO = C + CO_2.$$

This deposition is greatest at the top of the furnace and decreases lower in the shaft. It always takes place, however, in sufficient quantities to protect the lining at the top; the action on the other hand often disrupts the bricks lower down by acting on the ferric oxide contained in the clay. The beginning of the damage to a lining is heralded generally by the appearance of a hot spot on the shell some distance above the mantle. It is generally caused by faulty distribution of the charge over the furnace. This may result from the feeding device working unevenly, throwing, for instance, the coarse stuff against one spot until a channel for the blast has been made thither with the consequent eating out of the lining. The usual remedy is to put on a water spray to chill the walls so that the lining may be built up again by chilled slag or charge, particularly if the root of the evil is discerned. If the hot spot is due to the lining parting into a crack, "grout" or fire clay and water may be pumped in. Sometimes the alkaline carbonates and other alkali salts from a two or three basic silicate of low melting point deposit on the cooler part of the furnace, where it fuses prematurely with the lining.

The other sources of attack on the lining are mainly physical, due to the wearing of the charge against the side, and the physical attack of the slag and iron dripping on and gradually cutting the lining lower down.

Refractories in Coke Ovens. — To make coke, a coking bituminous coal is subjected to heat in a vessel in which the volatile constituents may distil and leave the fixed carbon and concentrated fixed impurities in the form of coke. The heat is always furnished by the combustion of the volatile hydrocarbons. The rest of these gases are wasted in the so-called beehive oven, but they are recovered, and the values of lighting gas, tar, ammonia and heavy oils realized in the by-product ovens. The strain on the two furnaces is of different kinds. The original beehive works intermittently in that a charge of coal is coked in from 60 to 80 hours, then cooled and withdrawn and the furnace is recharged. In the Belgian type of the beehive the chief modification is that instead of having one working door only, the oven has a door on each side. This permits of the whole charge being pushed out when coked, instead of being drawn or raked toward, and then out of, the only working door as in the original beehive. In the by-product ovens which are tall, narrow and long furnaces, heated on the long sides and sometimes underneath by gas, open at both short ends and charged from above, the coal is coked and pushed out into cars and a new charge dropped in about 18 hours. Thus this type of furnace is subject to sudden change of temperature; the heat on the long walls is intense and a refractory with an exceedingly high melting point is desired.

In the beehive a high temperature is obtained but the greatest strain is physical, due to the abrasion of the charge on the walls, especially when machine drawn.

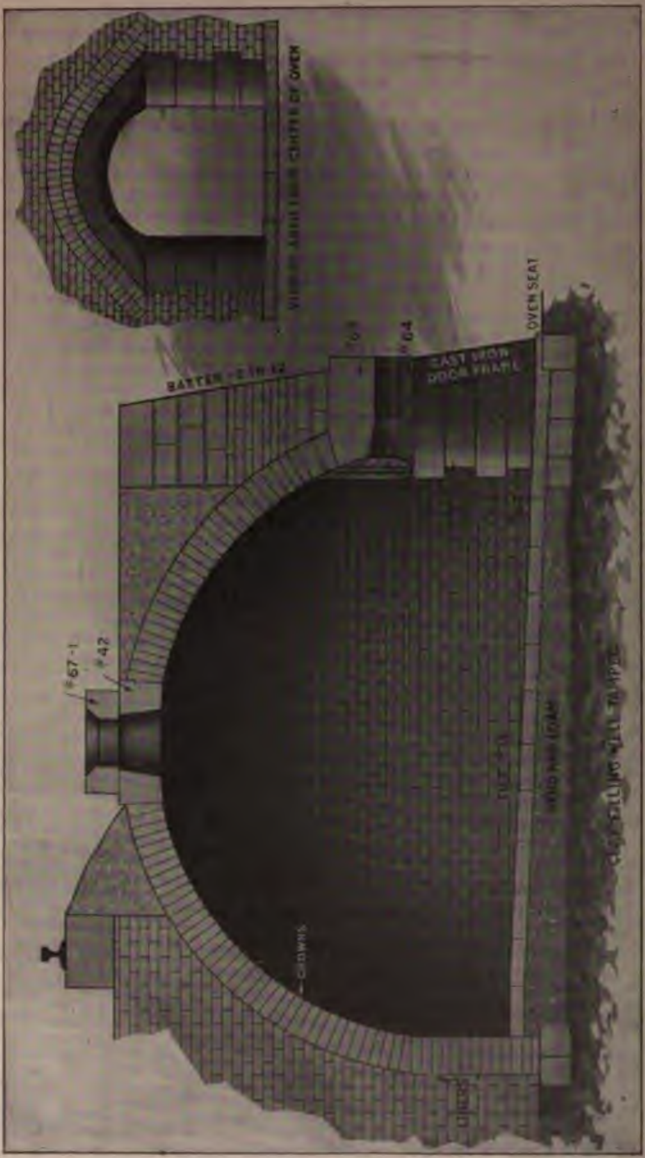

FIG. 48. — Beehive Coke Oven.

The beehive oven is shaped like its namesake, and is a section of a vertical cylinder about 12 feet 6 inches in diameter and 2 feet 8 inches in height, surmounted by a dome. The total interior height is about 7 feet. The walls or liners are made of high-grade fire-clay bricks, 9 by $4\frac{1}{2}$ by 4 by $2\frac{1}{2}$ inches. The crown of the dome, which has an exceptionally high temperature to withstand, must be made of material with small modulus of expansion and great resistance to any action from heat. Silica brick bonded with lime has proved the best for the purpose. These are generally 9 by $4\frac{1}{2}$ by $4\frac{1}{16}$ by $2\frac{1}{2}$ by $2\frac{1}{4}$ inches. The mortar used may be a mixture of ground quartz and plastic fire clay. The silica brick has a fairly constant coefficient of expansion and accordingly a very rigid crown may be made, by allowing the right sized joints to take up the known expansion. The fronts and floor tile are of fire clay. The foundations under the floor consist of a lowest foundation of well-tamped clay filling; above that and under the tile is a bed of sand and loam. The tile floor is made of sizes 12 by 12 and from 3 to 4 inches thick. The apex of the beehive through which the coal is charged is made of a hollow ring in sections or it may be a solid piece with a hole in the center: 23-inch top diameter with 13-inch clear diameter of hole and 21-inch bottom diameter

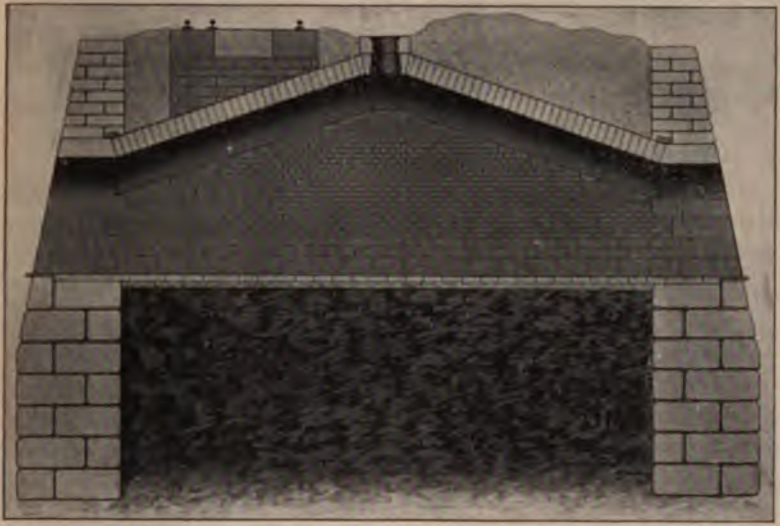

Fig. 49. — Belgian Coke Oven.

with 14-inch clear diameter of hole and 10 inches thick, or it may be made in a 12-piece section of like size over-all. The trunnels are made of either silica or fire clay. The operation of the furnace is relatively simple. The coal is charged into a hot furnace and the slow combustion for heating and producing degasification is regulated by allowing the air to enter through a small port above the working or drawing door which is closed with bricks luted with mortar during the coking period.

In the Belgian oven which is shaped more like a tunnel, a low arch forms the roof which is 7 feet 6 inches above the floor at the middle or charging hole and flattens out to only 3 feet 9 inches at the two end drawing holes. The same general character of bricks is used in the Belgian furnace as in the regular beehive. The lower part of the wall has a height of 2 feet 6 inches of 10-inch courses of fire-clay liners throughout the whole furnace. This represents the height of the wall which is covered by the coal or coke and which is inclined to frit into it and abrase it when being drawn. Then above this level there are 9 by 13½ by 4½-inch silica brick to the spring of the low roof arch where crown arch brick may be used. These roof brick are also made of silica with lime bond. An examination of the 9 by 4½ by 2½-inch lime-silica brick made by two representative companies resulted in the following figures: *

Chemical and Physical Analyses

SiO_2.	Fe_2O_3.	Fe.	Al_2O_3.	CaO.	MgO.	K_2O.
Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
(1) 93.92	0.79	0.55	3.07	2.55	0.18	....
(2) 96.00	1.14	0.80	1.12	1.69	0.12	0.12

Physical examination. Crushing strength in pounds per square inch.			Specific gravity, true, by volume.		Porosity, per cent volume.
Side.	Edge.	End.			
(1) 2345	1564	2119	2.21	1.78	18.58
(2) 2896	1044	7551	2.05	1.62	21.72

	Absorption, per cent weight.	Expansion, inches per lineal foot.	
	(1) 1039	0.188	
	(2) 1294	0.346	

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* Private communication.

Sometimes a quartzite brick, made by bonding and burning ground quartz with fire clay, is used. These are less physically strong and resistant to heat and are poorer conductors. A representative sample was tested and gave the following results:

Chemical Analysis

SiO_2.	Fe_2O_3.	FeO.	Fe.	Al_2O_3.	CaO.	MgO.	K_2O.	Na_2O.
Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
71.64	1.93	0.40	1.67	25.02	0.31	0.45	0.36	0.19

Physical Analysis

Crushing strength, in pounds per square inch.			Specific gravity, true, of volume.		Porosity, per cent volume.	Absorption, per cent weight.
Side.	Edge.	End.				
2139	528	297	2.35	1.95	12.37	8.24

Expansion, inches per lineal foot = 0.080.

After the charge is dropped the drawing doors are closed with bricks and luted with loam. The air is admitted through an aperture above the drawing door; gases escape through the charging door as in the beehive, or through special canals if the value or part of the value of the gases is realized by burning under boilers. After from 56 to 72 hours the doors are opened, the charge is cooled with a water spray and then drawn.

By-product Coke Ovens. — In all these ovens the coal is degasified in an oven separated from the heating chamber. In this they differ from the beehive in which the heat, to promote degasification, is generally produced in the oven itself by the combustion of some of the hydrocarbons in the coal; the amount of this combustion is regulated by the admission of air through a hole above the drawing door. The heating chambers of the by-product ovens are generally long canals beside, and sometimes also underneath, the coking chambers. These chambers are from 30 to 45 feet long, 16 to 24 inches wide, and 5 to 8 feet high, and a series forms a block of ovens.

Some of the various types are known as the Koppers, Otto-Hoffman and Semet-Solvay. In all types the walls form flues through which a portion of the gases pass and in which this portion is burned, thus heating the coal in the oven and effecting its degasification. The coal in the long narrow furnaces is thus quickly coked, speedily pushed out, and little heat is lost. The coal recedes toward the middle from the side walls in coking and assumes a regular physical structure, and has an uninviting, gray, lusterless look. It makes an excellent coke for smelting purposes and the process supplies large quantities of ammonia, tar and oils, in the form of by-products, which are extracted from the gases, during their passage from the oven through the cleaning and washing house to regenerative chambers and the flues. In these the combustion of the gases takes place and their heat is transferred from the canals which surround the oven proper to the coke with which it is charged. Silica bricks are used throughout the canals and ovens except in the checkerwork of the regenerative chambers which may be made of fire-clay bricks. Because silica brick and shapes expand uniformly, the oven walls last longer and since they have a greater heat conductivity than fireclay, quick coking is promoted. There is scarcely any department of metallurgy which requires more care in selecting and setting the

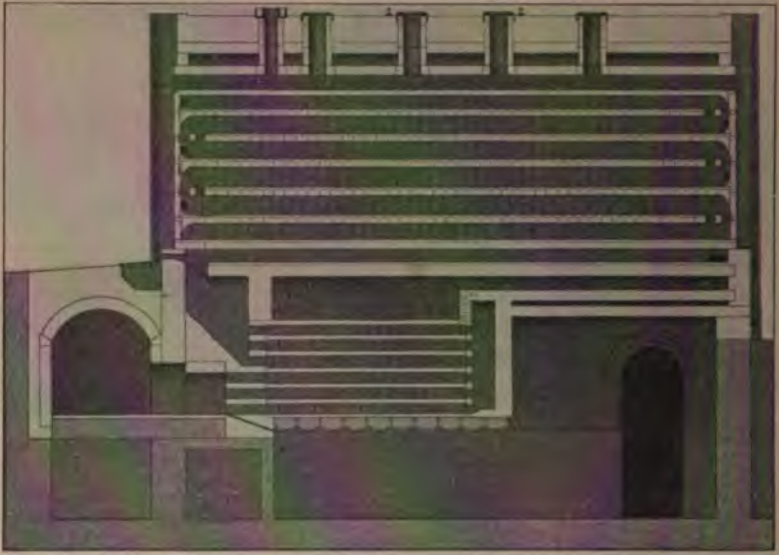

FIG. 50. — Longitudinal Section through Semet-Solvay Coke Oven.

bricks and hollow flue blocks. The manufacturers of refractories supply special plans for every new installation.

The progress and improvements in the construction of by-product ovens has been rapid, and they should be built by expert engineers.

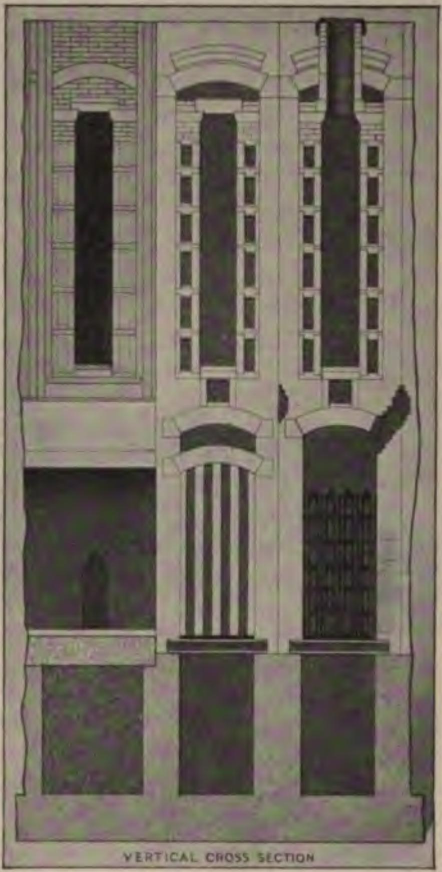

FIG. 51. — Vertical Cross Section of Semet-Solvay Coke Oven.

Steel Furnaces. — To make the pig into malleable cast iron which should be tough and yet mouldable, the white cast iron is heated, without being melted, in a reverberatory furnace with oxidizing agents, and the carbon is burned off. Often the white cast iron has already been cast; the cast objects are then placed in the furnace, freed of the greater part of their carbon and made tough and malleable. The oxidizing agent used is generally hematite, limonite, calcined magnetite or carbonate ore. On account of these oxidizing influences acting at a fairly high temperature, the linings are liable to be attacked, particularly when high in silica, forming ferrous silicates. Accordingly only the best brands of high-grade aluminous fire-clay bricks may be used in the process.

As far as the action of the ferric-oxide base is concerned the alumina fire-clay bricks act as a neutral salt, and do not allow the formation of ferric salts, with either silica or alumina or with both. The malleable furnace has a hearth of silica sand, sides and roofs of fire-clay bricks, and a fire box of second quality fire-clay bricks, with a mortar of mixed plastic and lean fire clay or of fire clay and loam.

Puddling Furnace. — To make the soft tough iron, known as wrought iron, the pig iron is melted on a hearth fettled with an oxidized slag and brought to the nature of purer iron by the oxidizing influences of certain agents, such as hematite, which are added; at the same time all the impurities are slagged off. The pig iron with 3 per cent carbon fuses at about 1100° C. which is about the temperature attained in the furnace, and becomes pasty on changing its alloyed condition to purer iron. The process is known as puddling and is carried out in a stationary reverberatory or in an oscillating gas-fired hearth known as the Roe furnace. Puddled iron always contains slag, which makes it tough.

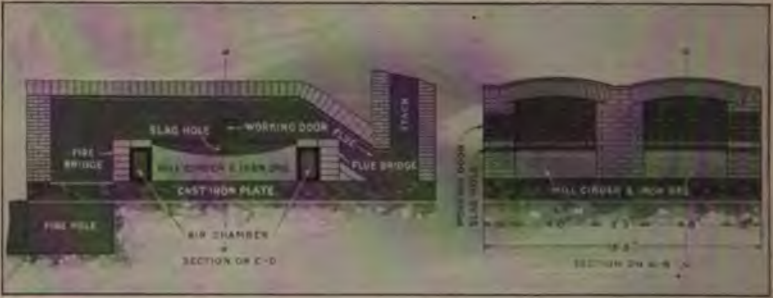

Fig. 52. — Double Puddling Furnace.

The hearth may be of magnesia brick on which a fettling of slag from the process itself may be sweated. The sides should be of magnesia to the height of the surface of the bath. The rest of the sides and roof are of fire clay.

Bessemer Converters. — Converting of pig iron to steel is effected with either a basic or an acid lining. In America the acid lining alone is used. In an acid-lined converter steel may be produced from pig iron which has a low phosphorus content, less than $\frac{1}{20}$ of 1 per cent. The converter is a steel shell lined with silicious mass (ganister) or blocks. The bottom through which the blast enters, which by combining with the silicon and carbon in the hot metal supplies sufficient heat to burn off and slag all these impurities, is composed of specially shaped blocks. These fit together in such a way that about 20 holes 6 inches in diameter are scattered evenly over the bottom. These are tamped with clay, and perforated with about 250 ½-inch holes to allow the passage of the blast.

Lining. — The lining is made of highly refractory acid material composed principally of silica. In England a ganister rock is used, or sometimes the lining is rammed around a pattern and is composed of silicious material held together by a small amount of fire clay. In America it consists usually of blocks of ganister or of mica schist (a silicious rock consisting of pseudostrata, or laminæ formed by tiny plates of mica) laid with a thin layer of refractory fire clay between, and in such a manner that the edges of the laminæ will be exposed to the wear to which it is subjected. The converter slags are always high in silica and corrode the lining only slightly. If, however, any uncombined oxide or iron comes in contact with it, it is attacked very rapidly. For this reason the mouths of the tuyeres are rapidly eaten away, and this part of the converter lasts only from 20 to 25 blows. The bottom is, therefore, fastened to the body with links and keys, so that it may be readily detached and replaced by a new one. Indeed, in some works bottoms are changed with an average delay to the operation of only about 20 minutes for each replacement.

Bottoms. — The lining of the bottom is made by placing the tuyere bricks in position and then filling in around them with refractory material consisting of damp silicious material held together with clay and containing usually some coke braize, which seems to lessen the chemical activity of the corrosion. The details of lining vary so greatly that no general rules can be given. The number of tuyeres is from 18 to 30, the number of holes in each from 12 to 18, and the size of the holes ⅜ inch (England) or from ⅜ to ⅝ inch (America). The correct lining is of the greatest importance and is the most influential factor in determining the life of the bottom, which furthermore depends upon the care in drying, the temperature of blowing, the pressure of blast and the composition of pig iron. A bottom should dry 36 hours or more. Its life is shortened by (1) hotter blows, (2) longer blows, (3) lower blast pressure (because the blast holds the metal away from the mouths of the tuyeres), and (4) more manganese in the pig iron (because a wet slag is more corrosive). Between heats, when the vessel is on its side receiving the recarburizer, pouring into a ladle, or receiving a new charge, the lining of the bottom can be repaired. For instance, if one tuyere eats away faster than its fellows, the excessive corrosion can be prevented by stopping it up with mud, because, if no air passes through the holes, no oxide of iron is formed at their mouths: or a worn tuyere may be replaced by a new one, etc. These repairs are chiefly made through the wind box, the back plate of which is removable.

When a bottom is worn out it is taken away and a new one brought on a car and placed under the converter, which is in the vertical position. Around the top is piled a ring of thick wet mud, and, as the bottom is forced up against the body by hydraulic pressure, the mud is squeezed into a firm joint.

The Basic Converter. — This vessel is very similar to the acid converter. The lining is made of mass generally either of calcined dolomite or magnesite. The bond used is hot tar which is admixed in a proportion of about 10 per cent of the mass. The whole mixture is rammed hot about a pattern. In tamping the bottom ½-inch wooden pins are rammed in with the lining, and withdrawn when the mass is sufficiently set. The lining must not enter into combination with the slag, but must resist its attacks. The oxides of phosphorus, silicon and sulphur combine with lime which is added to the bath just before blowing; the lime required is from 14 to 20 per cent of the weight of the iron. The slag is so rich in phosphorus, containing from 12 to 20 per cent phosphoric acid, that it may be used as a fertilizer.

The Cupola. — The cupola affords the cheapest means of melting metal for cleaning or making alloys because of the direct contact between metal and fuel and the accompanying maximum absorption of heat. It is, in reality, a small blast furnace, but instead of reducing ore it remelts metals and alloys for the steel and foundry industry, such as spiegel for the converter and open hearth and cast iron. All cupolas are round cylinders, with a lining of fire-clay blocks held in a steel shell. The inside diameter varies from 2 feet 6 inches to 5 feet in the clear. Special shapes of fire clay are made for all sizes, thus avoiding waste in cutting brick.

The Acid and Basic Open Hearth. — In the acid open hearth relatively pure pig, i.e., iron free from large quantities of phosphorus and sulphur, may be made into steel by oxidizing and burning off or slagging the impurities. The acid open hearth is used as a remelting furnace for toning all kinds of steel to certain requirements. In the basic open hearth, pig iron relatively high in sulphur and phosphorus may be made into steel since the basic converting process is not used in America or England. This basic open-hearth process has been widely developed, and in its development has advanced the study of refractory materials very considerably. The lining of the acid open-hearth furnace is generally of silica bricks. The bottom may be made of sand and clay mass, boshed in the side. The lining is gradually eaten out by the ferrous and manganous oxide, especially if there is not sufficient silicon in the original pig iron to make a silicate slag with the oxidized metals during the process of refining.*

Regenerators. — With the furnace are connected two pairs of regenerators which preheat the gas and air for combustion. The internal volume of each of these chambers is from $\frac{3}{8}$ to $\frac{9}{10}$ of that of the working chamber itself. The larger the chamber, the greater will be the amount of heat intercepted in it, and therefore the lower the temperature of the gases which go to the stack. The amount of space actually occupied by the bricks, or checkerwork, is the important consideration, however, and this should be from 5000 to 10,000 cubic feet for all four regenerators in a 50-ton furnace. The capacity of the two gas regenerators is usually less than that of the air regenerators, because the volume of gas

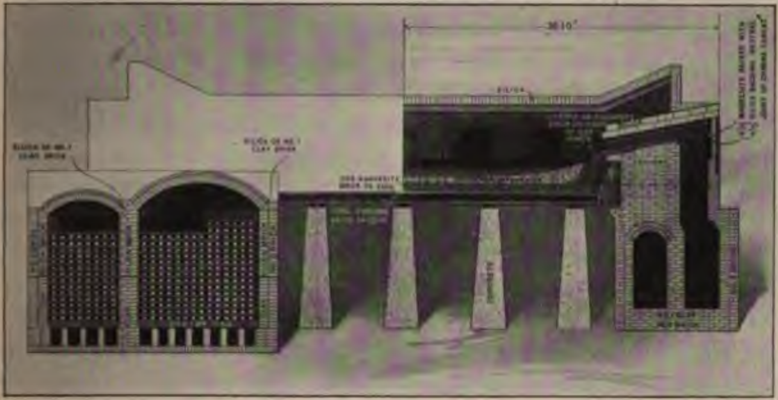

FIG. 53. — Basic Open-hearth Furnace.

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* From Bradley Stoughton, "Metallurgy of Iron and Steel," McGraw-Hill Book Co., 1912.

used is less than that of the air, and also because the gas does not require to be preheated so much, since it is already somewhat warm from the gas producer. During the operation of the furnace more or less slag, dirt and dust are carried over with the outgoing gases. To intercept this, slag pockets or dirt pockets are provided;* but in spite of them the space between the bricks of the checkerwork becomes partially choked, and for this reason the total area between the bricks must be much larger than the area of the ports, so that the velocity of the gas will not be lessened. On the other hand, the space is limited, because the bricks must be laid in such a way that the maximum amount of surface shall be exposed and the gases forced to the greatest possible contact with them. The furnace must be laid off for repairs when the passages between the bricks are choked by dirt. The modern construction makes the regenerators as tall as possible in order that incoming gas and air may be forced into the furnace by the draft, and also because this chimney effect causes the incoming gas and air to seek naturally the hottest places and the outgoing gas to seek the coolest places, in this way equalizing the temperature in the different parts of the regenerators.

The space underneath the checkerwork should be so large that the incoming gas and air will distribute itself uniformly through the different passages, and the temperature of the fire bricks at this lower part will be, say, 400° C. (752° F.), although varying, of course, with different furnaces and at different times. When the regenerator is receiving the waste gas from the furnace the temperature of these bricks will be that of the gases which go to the chimney, say 400° to 600° C., and when the air or gas is passing through the regenerator on its way to the furnace these bricks will be somewhat cooler, depending upon the length of time that the regenerator has been in this phase of the operation. The temperature of the bricks at the top of the regenerator will be about 1000° C. (1832° F.), and therefore the air and gas entering the furnace will be the same.

Ports. — The ports are so arranged that the flame shall be deflected from the roof and yet not impinge upon the bath, or impinge only very slightly, because the bath would thereby be oxidized excessively. The gas should be spread out over the width of the hearth beneath the air, and the two should be brought together just before they enter the laboratory or work chamber. The air, especially, must be kept away from direct contact with the bath, and for this reason the gas ports are placed below the air ports; this arrangement has the further advantage of promoting a better mixing of the two, since the gas is lighter and therefore rises. In America the favorite arrangement is two gas ports, above which is situated a long slit, extending almost the entire width of the furnace, which serves as an air port. This is not universal practice, however, for in some cases there are two or even three air ports. In one case the two gas ports are built wide and low, so that they will deliver thin streams and get a better mixing of the two materials for combustion. The area of the air port in a 50-ton furnace should be about 18 square feet, and the combined area of all the gas ports on one end should be from 8 to 10 square feet depending upon the quality of gas used.

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* Bradley Stoughton, *op. cit.*, p. 134.

The roof must be protected from the direct impact of the flame, because even the most refractory silica bricks would be melted by the intense heat. The heat in the regenerators and uptakes gives the gas and air a velocity which causes them to enter the furnace with some force, and the construction of the ports directs the stream in the desired manner. The mouths of the ports are gradually melted away by the intense heat of combustion of the outgoing gases, until they finally cease to serve this purpose, and it is impossible to get the proper mixing and the proper kind of a flame in the laboratory of the furnace. The ports must then be repaired, or the temperature cannot be maintained.

Draft and Chimney. — The draft must be sufficient to catch the flame about in the middle of the laboratory and drag it out through the ports on the opposite side from which it entered without allowing it either to drop down and touch the bath (as this is to be heated almost altogether by radiation) or to impinge upon the roof. This draft also has to do the work of overcoming the friction of the outgoing regenerators and flues. Its force will depend upon the height of the chimney and the temperature of the products of combustion after they have left the regenerator, which should be about 400° C. (752° F.), though even better economy (i.e., a lower temperature) than this is obtained in many cases. All the heat carried away by these flue gases is, of course, wasted, but the great cost of the refractory bricks in the regenerative chambers n [illegible] the temperature of the flue gases too much by enlarging the checkerwork.

Roof. — The roof is made thin and of the most refractory bricks that can be obtained, i.e., almost pure silica, with enough lime to hold them together in a compact mass. The walls are also thin, and the radiation from the furnace chamber is great, but this has to be endured, as thicker walls and roof produce endless trouble by expansion and contraction. The roof is arched and suspended from beams independent of the side walls.

Life of the Furnace. — The "life" of an open-hearth furnace means the number of heats that it can make continuously without stopping for any more extensive repairs than can be made in the usual week-end shutdown. No figure can be given for this except in the most general way. The life of the furnace will be ended usually in one of three ways; (1) the falling in of the roof, (2) the eating away of the ports, so that the flame can no longer be maintained properly, or (3) the giving out of the regenerators, which may occur either through the choking of the checkerwork, or through a crevice formed by the contraction and expansion of the bricks, so that there is a serious leak between the gas chamber and the air chamber, and premature combustion takes place. If a basic furnace makes 350 heats, it is considered good work, and we may perhaps tentatively consider this figure as the "three-score years and ten" of a furnace making steel for structural work and similar purposes. Three hundred and fifty heats would mean about 18 to 24 weeks' work in America. An acid furnace will last about 1000 heats.*

Construction of Hearth and Bottom. — The hearth is made with a thickness of 18 to 24 inches inside the furnace shell, in the form of a shallow dish whose sides reach up to the level of the charging doors, and so constructed that the depth of the metal will be from 12 to 24 inches, the former figure in the case of a very small furnace, say from 5 to 15 tons, and the latter in the case of one of 50-ton capacity. If the bath is too shallow the oxidation will be excessive and the wear of the lining by oxide of iron, with consequent production of slag, will be great; if the bath is too deep the melting and oxidation will be slow. In the case of an acid bottom the portion of the lining next to the shell will be made of refractory clay brick, and the upper portion will be formed by shoveling in silica sand, spreading it out in a thin layer about ½-inch thick over the entire hearth and then allowing it to sinter at the full heat of the furnace for about 10 minutes, to set it firmly in place. Upon this layer will be set another layer in like manner, until the whole hearth is constructed, and then it will be "washed" with a melted bath of old slag to fill all crevices and give a glazed surface.

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* Bradley Stoughton, "Metallurgy of Iron and Steel."

In the case of the basic hearth the bottom is made of calcined dolomite held together with 10 per cent or less of anhydrous tar. In this case the layer of bricks next to the lining is very thin and the dolomite and tar are set in layers by the heat of the furnace as in the case of the acid lining. The tar burns to a strong coke, which holds the mass together in a firm, hard form. In some cases no tar is used, and the calcined dolomite is fritted slightly to hold it together; in other cases 15 per cent of slag is used as a bond. Pure magnesia gives a more permanent lining than dolomite, and is now much used since its longer life more than compensates for its greater expense. Even when magnesia is used for the bottom, the topmost layer, or working bottom, and the repairs, or "fettling," put in during the intervals of the furnace life, are made of dolomite, because this sets more quickly. As the sides and roof even of the basic furnace are made of silica bricks, it is customary, although not absolutely necessary, to put a layer of neutral material between these bricks and the basic hearth, and also to protect this joint from excessive heat. The neutral material commonly used is chromite bricks, which are made of ground chromite (FeO, Cr_2O_3), held together with bauxite or such bond as tar and then burned to form a firm, hard mass.

Repairing Bottoms. — Between the heats, bottoms are repaired by filling holes with acid or basic material, as the case may be, and by more extensive attention at the end of the week. In this way the bottom may be made to last almost indefinitely, unless a part of the charge works its way down a crevice and forces up whole sections of the bottom lining, which not infrequently happens; sometimes the charge even works its way out through the bottom of the furnace. A sticky or viscous slag is also liable to bring the bottom up by sticking to it. In the tilting furnace the bottom may be repaired along the point where the worst corrosion usually takes place, i.e., at the [illegible] slag line, even during the operation, by tipping the [illegible] is uncovered.

Tap Hole. — In the stationary furnace the tap hole, during the operation, is closed by material rammed into it from the door of the furnace. It sets quickly into a solid mass, which is pierced with a pointed bar when it is desired to allow the metal to run out. After tapping the hole must be entirely freed from metal, and then it is made up and filled anew, ready for the next operation. This always delays work to some extent, and occasionally the tap hole causes trouble by the charge working through it prematurely, or, on the other hand, by its becoming so hard that a hole is pierced in it only after a long delay and much difficulty, during which the oxidation continues in the charge beyond the desired point. In the tilting furnace there is no tap hole, strictly speaking, but the opening into the metal spout is closed by loose material, which is scraped away before the furnace is tipped to pour the charge.

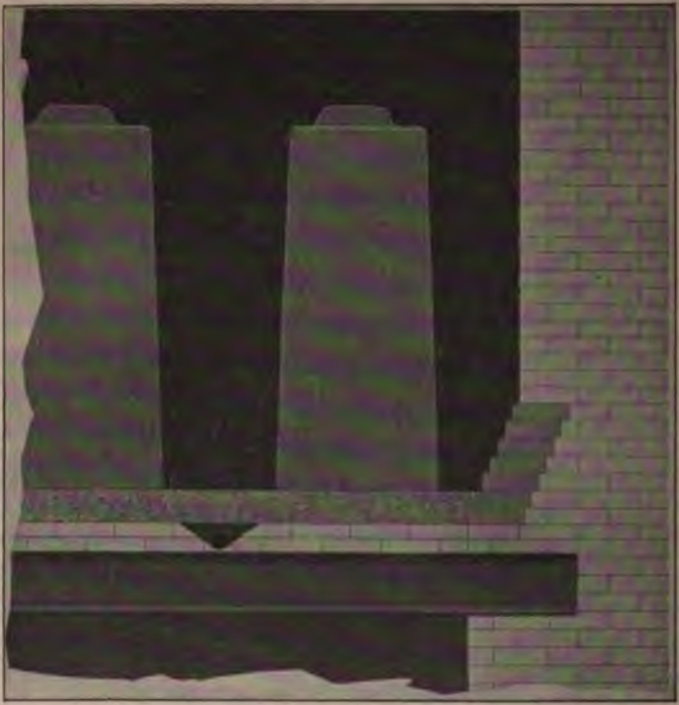

FIG. 54. — Soaking Pit. Chrome Brick used on Small Bosh (indicated by Shaded Bricks).

The Soaking Pit. — This is the name given to the furnace in which the steel ingots are kept hot when they are awaiting their turn in the rolling mill. It is a long furnace about 4 feet 6 inches in width and 6 feet deep, with regenerative gas firing. The foundation of fire bricks on steel rails holds the hearth of coke dust. The sides are boshed slightly at the bottom; the bosh is sometimes made of chrome brick, often of fire-clay brick. The rest of the furnace is of good fire-clay brick.

The crucible furnace in which the special steels are made by smelting mixtures in graphite crucibles is now often made of silica blocks or shapes, although first-class fire clay may often prove satisfactory. Silica should, however, be used about the pot hole. A hearth to hold six pots is generally three feet long and three feet wide at the bottom, tapering up to two feet at the top. The hearth is heated by regenerative gas firing and provided with covers.

CHAPTER VII

REFRACTORIES USED IN THE METALLURGY OF COPPER

UNTIL recently the standard type of roasting furnace in a copper smeltery was a long horizontal chamber with a fire box at one end and a flue for the escape of the gases at the other; the ore might be charged through a hole in the roof at the flue end, through a number of charging holes in the roof, or through doors on the side. The chamber might be stationary or a revolving horizontal cylinder. In the former the shape is rectangular; the floor, of fire-clay bricks is set on a foundation of convenient depth, made of coke braize, of slag and ashes, or of old brick bats; the side walls and roof are often built of second-class fire-clay bricks, while the fire box and the hearth or floor, which is near the fire or is exposed to high temperatures or corroding attacks, may be made of first-class fire-clay, magnesia or other good refractory bricks. It is understood that reverberatory roasters alone are being discussed. In smelting and refining furnaces such materials as silica and magnesia are used. Even in roasting furnaces magnesia is, under certain conditions, advisable for the whole hearth. The average roasting furnace is from 60 to 80 feet long and from 14 to 16 feet wide inside. The small oxidizing and dry-reducing furnaces in chemical factories are much smaller and vary in size from a length of 10 feet and a width of 5 feet and up. The particular process demands, always, a certain kind of refractory for hearth, walls and roof. Silica is nearly always satisfactory in the roof at the temperatures employed in such furnaces. It may not, of course, be used when liable to the attack of basic fume, dust or slag.

Mechanical Roasting Furnaces. The revolving horizontal type of furnace includes such classes as the Brueckner, the White-Howell roasting furnaces and the long driers and calciners of the kind familiar to cement makers. The former are generally lined with fire-clay brick, while the latter which are now made as long as

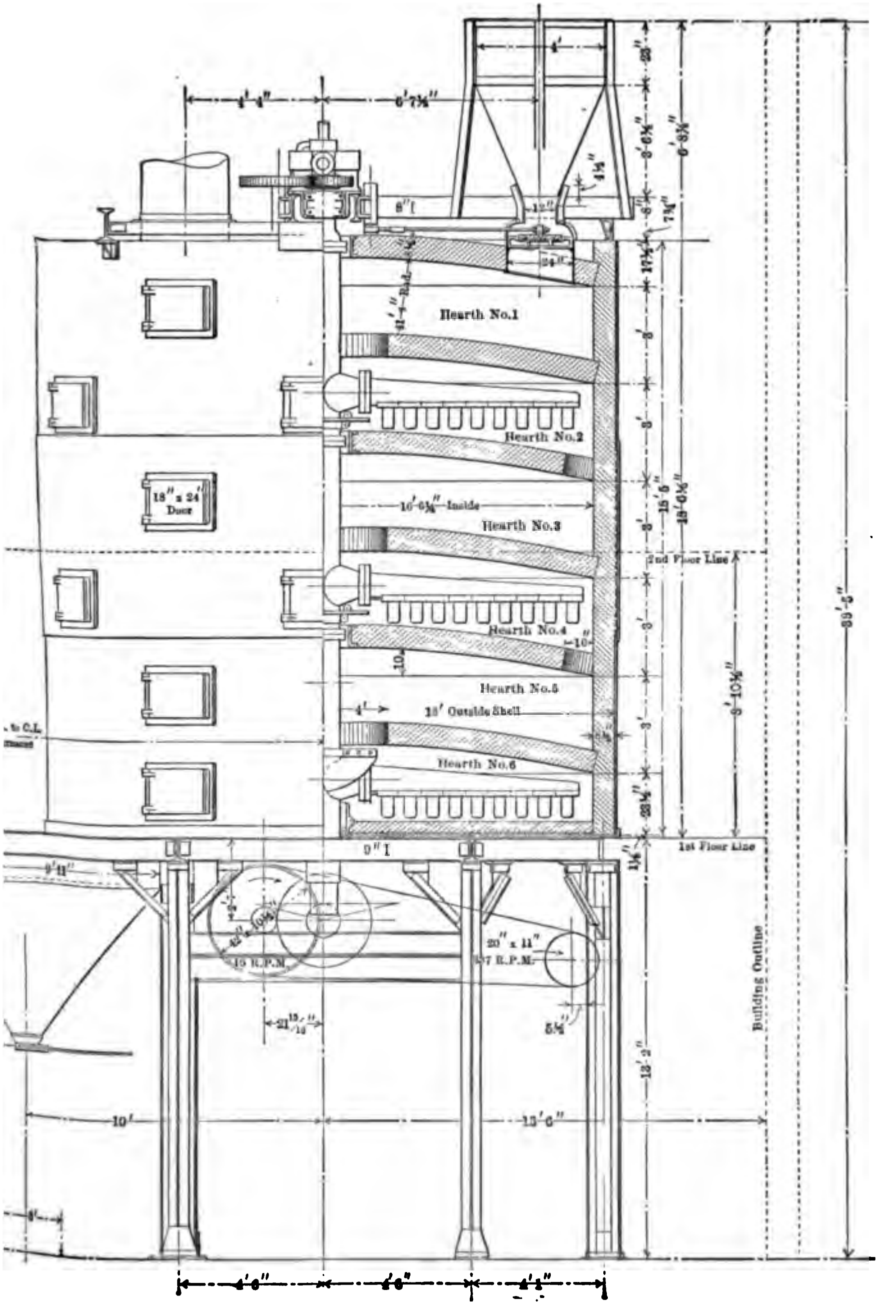

Fig. 55. — The McDougall Furnace (Evans-Klepetko Type).

160 feet and have a diameter of 8 feet are more, often lined with silica, bauxite or even magnesia brick. The lining is generally built 6 inches thick of bricks, especially made and shaped for the shell of the calciner. The Wedge, Herreshoff and McDougall furnaces are all modifications of a vessel involving the same general principle of roasting, that is, a series of superimposed hearths. On the topmost of these the hot ore is charged, stirred and moved in thin layers around the hearth. It then falls either at the periphery or center to the next hearths where the stirring and oxidizing is continued until the ore is sufficiently desulphurized or oxidized. The hearths and tile which sometimes surround the inner shaft which revolves and carries the rabble are made of fire-clay bricks. The walls are either good red or fire clay. The 6 holes at the periphery through which the ore falls are lined with fire-clay brick. Sometimes the lower hearths are of magnesia. The Wedge furnace is sometimes built completely of magnesia. The outside steel shell is of $\frac{3}{8}$-inch or $\frac{1}{2}$-inch metal and provided with sufficient working doors. For full descriptions the reader is referred to the "Practice of Copper Smelting" by Dr. Peters, pp. 84 to 88.

The inside lining of 9 inches above the jackets is of fire brick, the outside $13\frac{1}{2}$ inches of red bricks or of fire bricks. The crucible may be lined with magnesia or with fire-clay bricks; the outer wall should be of second quality fire bricks.

Smelting. The roasting furnaces present no such problems as those encountered in designing furnaces for smelting. The charge in roasting is never in such a condition of fusion that the furnace walls are not exposed to the severe attacks, physical and chemical, which baths of molten metal, alloys and slags make on linings. It is true that material in the process of sintering and fritting will seriously affect the lining and hearth which it touches. This action is more of a physical than of a chemical nature. In the process of sintering the ore frits to the brick and forms slags and salts with whatever silica and alumina with which it comes in contact. When cooling and contracting the sintered ore may thus disrupt the inside lining and hearth or, and this is probably more often the case, the workman may force the ore from its position and with it some of the brickwork. The gases in a roasting furnace may seriously attack the roof. Volatilized lead and zinc oxides may form silicates which are fusible in the higher temperatures obtained near the fire bridge; but, on the whole, the roof of a roasting furnace lasts very well.

The smelter in deciding the merits of many issues placed before him daily, must consider seriously the matter of refractories. In the first place, if he is constructing a new plant and is weighing the relative merits of direct smelting on the one hand and of wet concentration, roasting and reverberatory smelting on the other, he must know something of the effect of the slag on the lining he intends to use, before he may submit, to a board of directors, the comparative estimate of costs. Up to the present time the reverberatory smelters, almost without exception, have used silica in the hearths and roofs of the furnaces, and often use fire-clay bricks on the side walls, between the slag line and the spring of the roof arch. The range of materials adapted to smelting in reverberatory furnaces has always been limited in the smelter's mind by a consideration of the effect of an ore in question on a silica lining. Thus lime is not used in reverberatory furnaces because calcium silicate or calcium ferrous silicate may form at the expense of the lining. We must have, already in the ore, a neutral or acid slag mixture. Even with iron alone, as a base, in the slag there must be sufficient silica present to make a bisilicate. Even so the silica lining is attacked rather viciously by the slag in the effort to satisfy the demand of the ferrous oxide for still more silica and must be repaired from time to time by the process of "claying" the boshed hearth. There does not seem to be sufficient justification for specifying silica linings only in present reverberatory practice. Magnesia bricks of first-grade quality, made by reputable firms, are burned at a temperature of 1700° C. which is at least 200° above that obtained in the reverberatory. Calcined magnesite, of a quality which should resist effectively all chemical and physical attacks of the reverberatory process, might be employed for fettling and for the floor and boshed sides of the hearth.

In plants which use both blast furnaces and reverberatories the question of the proper furnace to handle the jig concentrates is sometimes raised. It is always settled by the reverberatory foreman insisting that he must have all, except the coarser first-class, concentrates. The blast furnace may need iron, the reverberatory could do with less, particularly if the difference were replaced by lime. But the reverberatory smelter is fearful of lime, partly be-

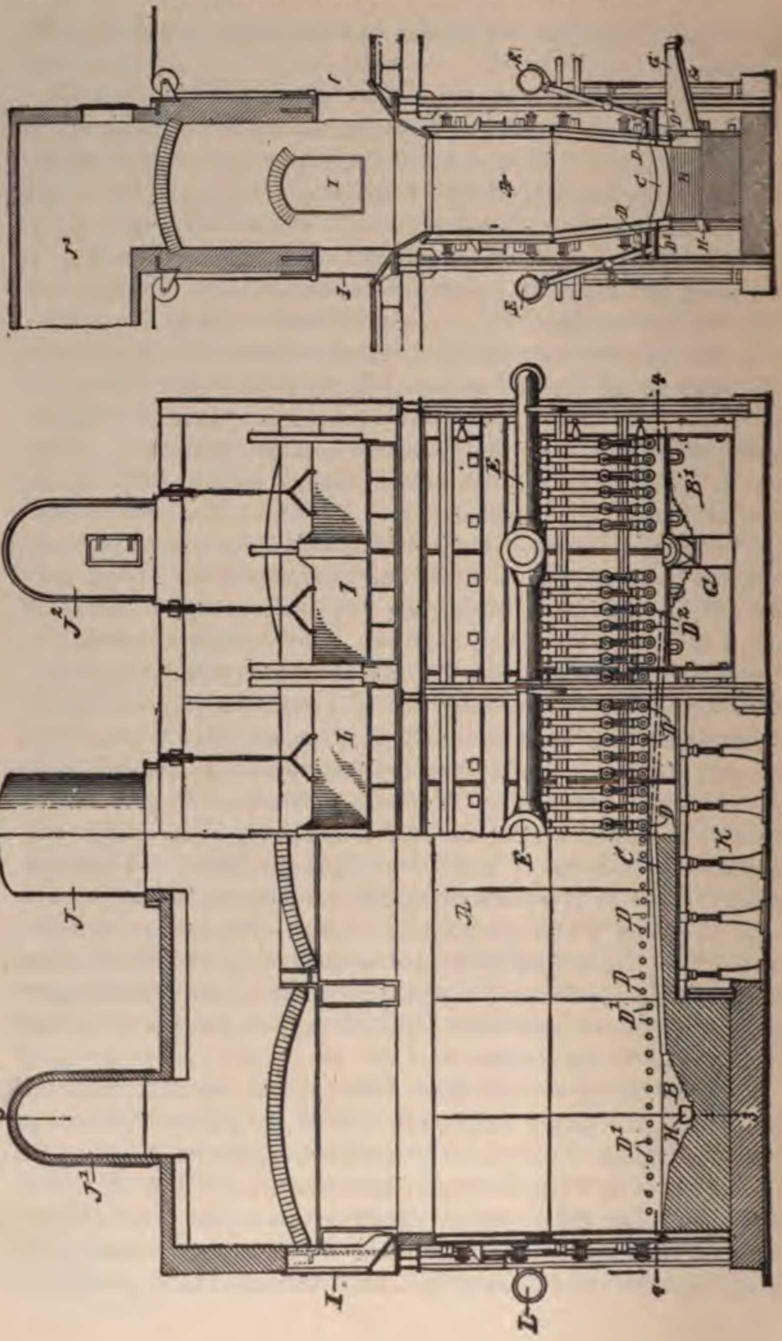

FIG. 56. — Copper Ore Blast Furnace at Anaconda.

cause a lime iron slag chills more readily than a straight iron silicate, but principally because the addition of any such base is a menace to the life of the usual type of lining. The division of the iron spoils might be considerably altered if the lining of reverberatory were different. Yet in using magnesia the smelter must remember that it is a good conductor of heat. It should only be used as a lining inside a wall of fire-clay brick. For certain purposes, such as cupelling lead-silver bullion, the furnace walls are made entirely of magnesia, but in such cases the furnace sides are often water cooled by jackets.

The blast furnaces are generally water jacketed from crucible to charge floor, or in some cases the top 4 feet of shaft below the charging floor, as well as the stack of shaft from the charging floor to the downtake are of brick, resting on a mantle which is carried on cast-iron columns. In the latter case one series of vertical jackets from 7 to 10 feet in height is used. If the jackets are carried to the charging floor a series of horizontal jackets superimpose the lower vertical tier. In either case the charge cannot attack the walls, and the metallurgist makes up the charge without any consideration of action between side wall and slag. He devotes his particular attention to the crucible which is more often made with brick walls inside a steel shell, resting on a hearth of bricks laid on a cast-iron bottom plate.

The crucible should be kept filled, to the slag spout, with matte, which has less action on fire-clay bricks than slag. Even when it is possible to do this it has been found safer to make the hearth walls, both above and below the junction of matte and slag, of magnesia bricks. The hearth may be, and generally is, made of fire-clay bricks. In the shaft of the furnace above the jackets the walls are, in the smaller class of furnaces, 22½ inches thick; the inside lining of fire bricks, which is generally 9 inches thick, is included in this. The walls of the crucible are generally 9 or 13 inches thick; they are made completely of magnesia bricks or of fire-clay bricks. The bottom of fire-clay bricks, is 4½ inches or 9 inches thick when the crucible is built on a bottom plate. In cases when the crucible is built from the floor of the smeltery house the foundation may be of second-class or ordinary fire brick. If the crucible is large it may be found advisable to make it 18 inches in thickness, when only the inside 9 inches would be of magnesia or fire-clay bricks; the outside course would be made of a second quality fire bricks.

Settler. — This should be lined with magnesia or chrome bricks. The matte tap hole which is easily corroded, particularly when working with nickeliferous copper ores, should be made of chrome or carbon blocks, of solid cast iron, or of water-cooled copper, cast iron or cast bronze.

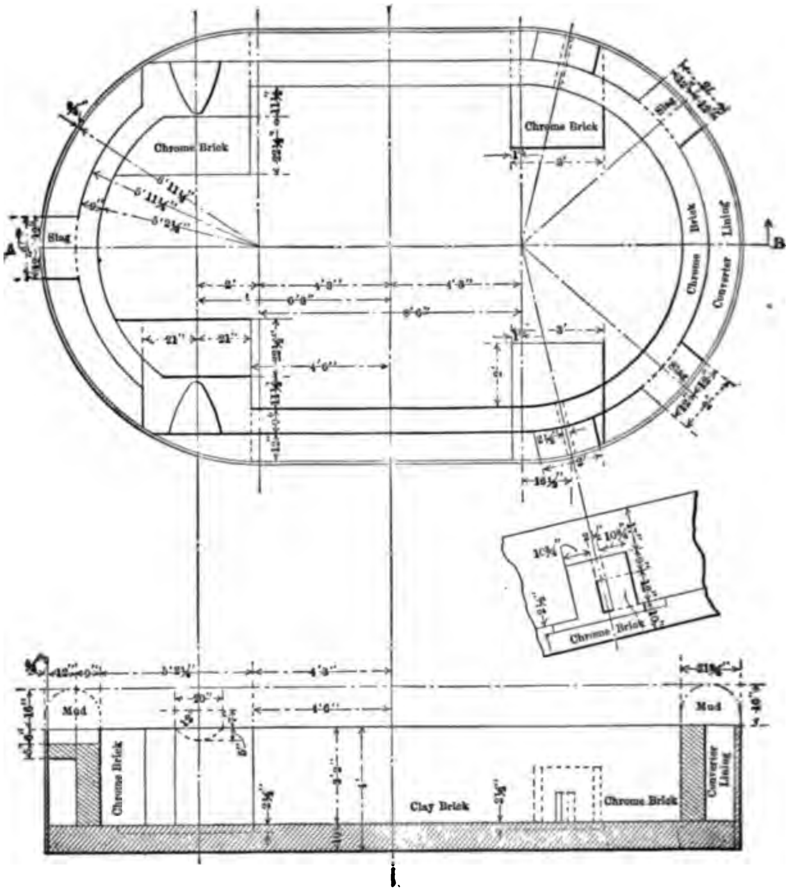

FIG. 57. — Settler at Cananea.

Linings of the Cananea Blast-furnace Settlers.* — The bottom of the settler is made of first-class fire-clay brick, laid on end; it is, therefore, from 9 to 10 inches thick. The upper 2½ inches are replaced, under the spouts and around the tap holes, by chrome bricks. The shell of the settler is of ¾-inch steel plate. The lining does not abut against this shell, but a space of 12 inches is left between and this is filled with a mixture of crushed quartz and clay such as is used in converter linings. This so-called "converter lining" permits the expansion of the chrome brick, which is considerable, namely 0.70 inch per foot, compared to fire-clay brick, which is 0.042 inch, and to silica brick, which is, on an average, 0.2 inch when all are heated to a temperature of 1650° C. Chrome brick is also a relatively good heat conductor (the modulus of thermal resistivity is 42 compared to fire-clay brick, 57, to silica brick, 120, while with magnesia bricks it is 34, in Ohms' centimeter cube at 1000° C.*), and the lining takes up and holds the heat conducted by the chrome bricks. While magnesia is preferred in converter linings, chrome is found to be more satisfactory in settlers. Yet, it has been generally conceded that both magnesia and chrome bricks last better if the outside is cooled, and in Cananea a spray pipe is sometimes used upon the outer shell. In almost all cases it is advisable to use water jackets or cooling sprays on the shells of all settlers and reverberatory furnaces in which the lining is of magnesia or chrome bricks.

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* The method of lining these settlers is discussed by Dr. Peters in "Practice of Copper Smelting," Chap. 9, of the edition of 1911.

At Anaconda 3 settlers are provided for the large blast furnace which is 87 feet by 56 inches at the tuyeres, and 2 each for the smaller furnaces. These measure in cross section 51 feet by 56 inches. These settlers are formed of half-inch steel plates and are 16 feet in diameter and 5 feet high.† They are lined with 18 inches of silica brick, and have a filling of 4 inches of crushed quartz between the shell and the brick lining. The bottom is formed of 12-inch silica brick laid on end, and is covered with a thick layer of crushed quartz. A perforated sprinkler pipe surrounds the outside shell, but is used only when the settler is too hot. A settler lasts for several years, but requires repairs about every three months at the front side, and in the region of the matte tapping hole. This repairing takes about 20 minutes to effect, and is accomplished by allowing the settler to become nearly full of matte, closing the trap spout and then tapping the settler clean. Crushed quartz is then tamped in the corroded and worn places by means of bars. The two matte tap holes are in massive

* Silver on this scale is 0.24.

† Peters, "Practice of Copper Smelting," p. 273.

uncooled cast-iron blocks, 4 inches thick. The temperature in the settlers is between 1200 and 1300° C.; of the matte when tapped 1240° C., of the slag at the overflow 1290° C.

The walls of many of the large circular settlers are mad of fire-clay or silica bricks held inside a steel sheet. For fu dimensions and particulars of different hearths the reader is referred to "Practice of Copper Smelting," p. 132.

Reverberatory Furnaces. — The quantities treated in these furnaces are large; as much as 275 tons is smelted per day (o 280 pounds per square foot of hearth area per day) on a hearth with a width of 19 feet and length of 115 feet heated by coal burned in a fire box 8 feet by 16 feet.

Table Showing Development of the American Reverberatories from 1878 to 1910*

Year.	Dimensions in feet.			Area in square feet.			Ratio between		
	Stack.	Fire box.	Hearth.	Stack.	Fire box.	Hearth.	Stack.	Fire box.	Hearth.
1878	2.75	4.5 ×5	9.66×15	7.56	22.5	105	1	2.98	13.9
1882	2.75	4.5 ×5	10.33×17.83	7.56	22.5	139	1	2.98	18.4
1887	3	4.5 ×5.5	12.67×21.17	9	24.75	198	1	2.75	22
1891	3	4.75×6	14.17×24.33	9	28.5	265	1	3.17	29.5
1893	3.5	5 ×6.5	16 ×30	12.25	32.5	402	1	2.65	32.8
1894	4	5 ×6.5	16 ×35	16	32.5	481	1	2.03	30
1903	5.5	5.5 ×10	20 ×50	30	55	840	1	1.83	28
1910	.....	8 ×16	19 ×115	.....	128	1967	No independent stack.		

Year.	Ratio between		Per cent hearth, area lost in corners.	Ore smelted per 24 hours — tons.		Coal per 24 hours.			Tons ore smelted per ton coal.	Pounds ore smelted per sq. ft. hearth per 24 hours.
	Fire box.	Hearth.		Cold ore.	Hot ore.	Tons.	Per cent coal for cold ore.	Per cent coal for hot ore.		
1878	1	4 67	28	12	..	5	42	..	2.4	229
1882	1	6.18	24.5	17	..	7	41	..	2.43	245
1887	1	8	26	24	..	9	37.5	..	2.67	242
1891	1	9.3	23	28	..	10	36	..	2.8	211
1893	1	1.37	16	35	43	13	37	30	2.7–3.3	174–213
1894	1	14.8	14	.	50	13.5	..	27	3.7	208
1903	1	15.3	16	42	70	36	..	..	3.1	267
1910	1	15.4	10	..	275	59	.	..	4.66	280

* Peters, "Practice of Copper Smelting", p. 326.

This roof should be constructed of 15-inch or 20-inch silica arch bricks. The whole arch should spring against horizontal I-beams

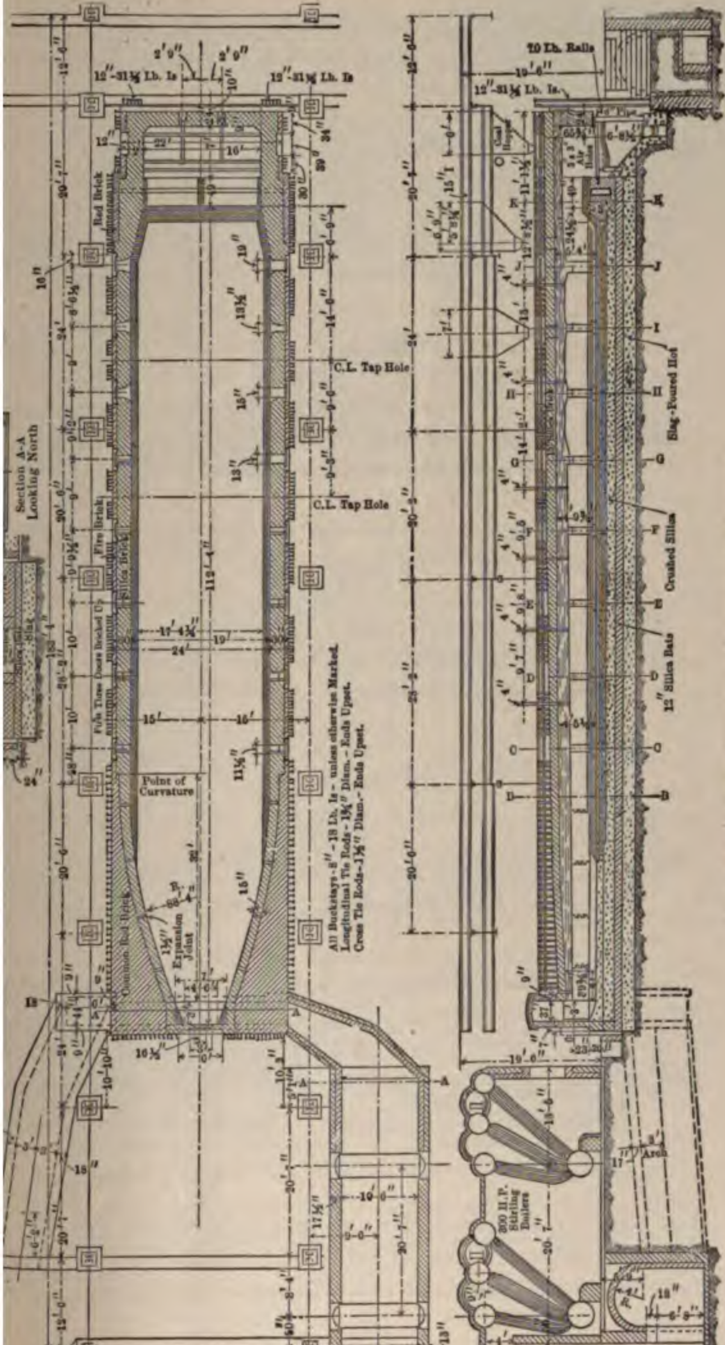
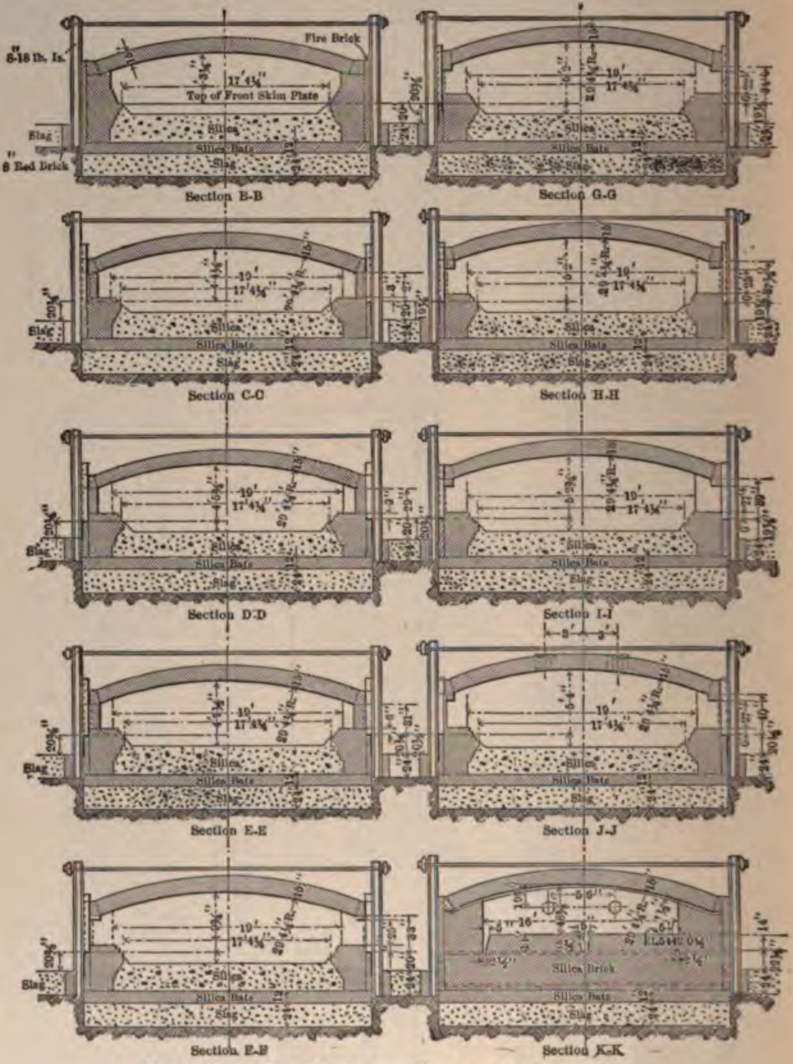


FIG. 58. — Reverberatory Furnace at Anaconda.

which are held in firmly by the upright buckstaves. The buckstays are tied together across the top of the furnace by means of



Section B-B

Section G-G

Section C-C

Section H-H

Section D-D

Section I-I

Section E-E

Section J-J

Section F-F

Section K-K

FIG. 59. — Reverberatory Furnace at Anaconda.

1- or 2-inch round tie bars which may be provided with several expansion joints. In smaller furnaces the buckstaves may have the form of channel irons; these are bored at the top and generally at the bottom. The tie rods are held by nuts which may be loosened as the furnace expands on being heated. Sometimes the buckstay is held in the concrete, stone or brick foundation at the bottom and tied only across the top.

In the construction of the hearth the improvements in Anaconda and Cananea are noteworthy. In former practice the bath was made of quartz sand; the sides and walls were of fire-clay bricks built up straight and vertical from the bottom. The corroded walls were repaired every 10 days during the campaign of the furnace by "claying," i.e., throwing silicious clay from the working doors across to the sides of the furnace where the heat would make the first layer frit and the succeeding shovels of sand in falling would form a bosh toward the bottom.

This tedious work is eliminated in the newer types by making good thick shelving banks of sand on either wall on which the stream of slag and matte laps; by keeping a layer of silicious ore at the point of contact and by "claying" or "sanding" by means of a hopper, which, running above and the whole length of the furnace, drops sand through evenly spaced holes in the roof, to the sides of the hearth which have been attacked by the slag.

In the construction of the new reverberatories in Anaconda the foundation of 2 feet of poured slag is covered with 1 foot of carefully laid old fire bricks. This height is the floor level. The walls of the furnace are 3 bricks thick, the outer is of red and the lining is made of 2 silica bricks. (These are manufactured of pure white quartz ground to pass a $\frac{3}{16}$-inch screen, pugged with 2 per cent of slaked lime. The brick is formed, pressed, steam dried, repressed and burned.)

These walls when 12 inches high step out, increasing the thickness of the wall up to the slag level or top of skim plate. They then decrease by stepping back from the maximum thickness of 3 feet 10 inches to 2 feet 6 inches. The wall above the hearth proper is only one brick thick for the greater part of the length of the furnace, the roof is 15 inches thick except over the fire box and for 30 feet from the skimming end where it is 20 inches. All bricks, except the above-mentioned red bricks, are of silica. These are said to expand roughly about 1 per cent in all three directions under the normal conditions and temperature of the smelting campaign, and thus the mechanics can loosen and tighten the tie bars systematically.

The hearth extends up to the maximum thickness of the side wall and is made of sand tamped hard and thoroughly "sweated." Three hundred tons are required to form a bath 26 inches thick on a hearth 19 feet wide by 100 feet long.*

In Anaconda, Dillon quartz with 92 to 95 per cent SiO_2 crushed to ½ inch is used. It is tamped and gradually heated until the top layer is slightly agglomerated. This is accomplished in from 6 to 7 days of careful firing.† During this time close attention is paid to the slacking of tie bars and expansion joints. The roof rises 2 inches. The plastic crust of the silica hearth is hardened

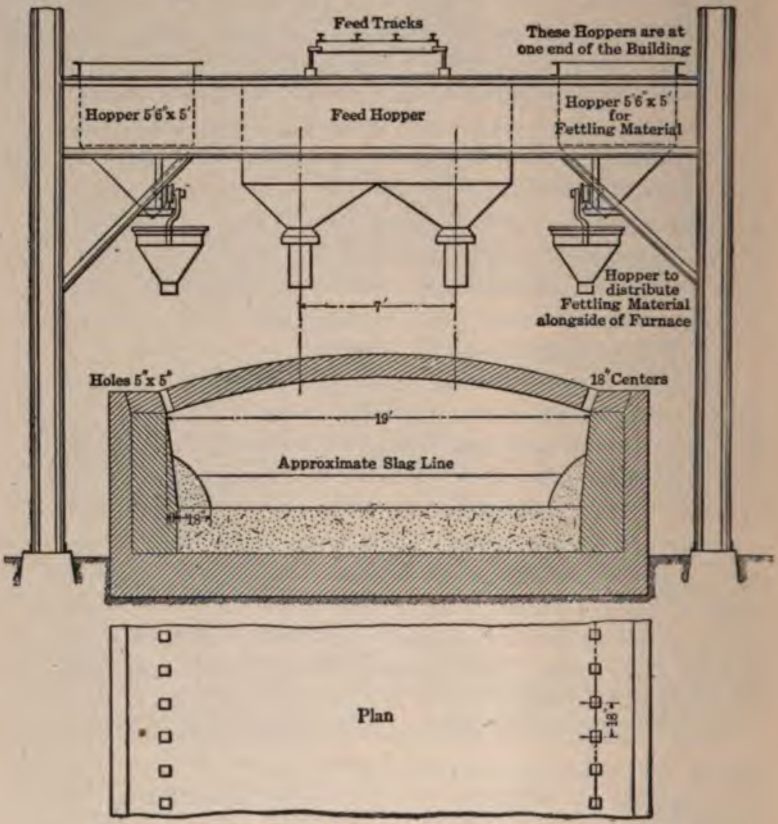

Feed Tracks
These Hoppers are at one end of the Building
Hopper 5′6″x 5′
Feed Hopper
Hopper 5′6″x 5′ for Fettling Material
Hopper to distribute Fettling Material alongside of Furnace
7′
Holes 5″x 5″
18″ Centers
19′
Approximate Slag Line
18″
Plan
18″

FIG. 60. — Method of Claying Furnace at Cananea.

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* Peters, Practice of Copper Smelting, p. 333.

† Op. cit., pp. 331 and 329.

by cooling somewhat, then is covered with 3 inches of smelter material of which a part is oxidized ore. The heat is increased again, the bottom is fused, and the regular sulphide charges started and maintained for 2 weeks in order to saturate the hearth with matte. A furnace after a campaign of 4 years in which it may have smelted 350,000 tons shows a wearing of about 2 inches in the bottom so that a normal life may be reckoned as 10 years.

In Cananea, claying or sanding of the furnace is effected by a travelling hopper dropping the sand, which is in reality fine wet silicious ore, through a pipe into holes five inches square, spaced at intervals of 18 inches in the roof, on to the boshed sides of the hearth.* This ore melts, trickles down the side walls and builds a sloping bank against the wall. It is then tamped firmly. Except during the daily process of fettling the roof holes are closed with fire bricks and fine ore. Ten to fifteen tons of silicious ore are used daily in fettling.

Tap Holes. — The orifice of the tap hole is closed by a fire-clay plug. A sharpened iron rod is driven through and kept "moving" between taps by gently hitting it with a hammer every 5 or 10 minutes. If the tap hole "freezes" the bar is knocked out, and the hole chiseled free with hand or air drills. When the soft interior is reached the bar is again inserted.

The two matte tap holes are generally near the bridge; but with gas-fired furnaces they are in the middle. The level of the tap is retained by means of a tapping plate or slab of converter copper 24 inches square and 2½ inches thick which is pierced by the hole. The slag is removed above the level of the cast iron skim plate on which a dam or bay of sand or limestone is built. When the slag is ready to run, the top of the dam is broken off until it is low enough to allow the slag to pass over. The slag eats its way down or the dam is cut until the required amount of slag has run out, when the slag hole is dammed up again.

The use of settlers is not general with reverberatories. They may be lined with fire-clay or magnesia bricks. Magnesia has not been applied in copper reverberatories as generally as might have been expected. Silica is cheaper and physically stronger, and the use of the boshed sand fettling prevents very great corrosion. Nevertheless, there can be no doubt that a hearth of strong well-burned magnesia would in the end be more economical than any other material. Both brick and mass of magnesia are made of such quality now that there is no reason why they should not be used with safety and economy in reverberatory hearths.

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* Peters, Practice of Copper Smelting, p. 339.

Refractories Used in Converting Copper Matte. — In converting copper matte the metallurgist wishes to burn, by means of the oxygen in the air blast, the sulphur and iron contained in the molten copper-iron-sulphide and, by the elimination in a similar way of any other impurities which oxidize more readily than the copper, to obtain finally an alloy of copper, with precious metals and traces of foreign metals and metalloids, which is known as blister copper. The sulphur in burning escapes as SO_2; the burned iron, in the form of ferrous oxide (FeO), must be given an acid companion to slag it. This companion is silica which, until quite recently, was provided by the lining of the converter. This lining was, at one time, made of ground quartzite burned with clay in the proportion of 75 per cent of the former to 25 per cent of the clay. More recently it has been composed of such mixtures as copper precipitate, concentrates and sand, or silicious ore, second-class ore and pond slum, tamped to a thickness of 12 inches against the shell. Such a mixture consisted approximately of:

	Per cent
Al_2O_3	10–12
SiO_2	60–70
Cu	3½
FeO	5
S	5–8

The iron silicate, resulting after the combination of the ferrous oxide with the acid of the lining, contained approximately:

	Per cent
SiO_2	20–35
Al_2O_3	1– 8
FeO	55–61
S	1
Cu	2

It was natural that the life of the silicious lining could not be long, and although the realization of the advantages of a lining which would be resistant to the attacks of the ferrous oxide and silicate has long possessed metallurgists, efforts made in the eighties and nineties to replace the acid by a basic lining were frustrated on account of the insufficient knowledge of the physical properties of basic materials. Magnesia was tried in the linings of the conventional small vessels, and conducted the heat away from the bath so rapidly that this chilled while the bricks spalled under the strain. Difficulty was experienced in feeding the acid companion for the ferrous oxide, whether this was done through the tuyeres or by way of the mouth of the converter. With increased knowledge of the properties of magnesia brick both the manufacturers and metallurgists have been able to develop the basic-lined converter and to establish its supremacy as a cheap producer of copper. The Styrian magnesia, which is used generally in American fire-brick factories, when thoroughly pugged and tempered, makes a brick which develops surprising strength when carefully burned at a temperature of 1700° C. By the use of large vessels the heat conducted by the magnesia is less per pound of bath and per pound of magnesia. The bath, therefore, does not chill, neither do the bricks spall. Nevertheless, some of the smelteries, notably Anaconda, have achieved considerable success by converting with a magnesia-brick lining, in the old-fashioned standard size of barrel converter. The lining is made 18 inches thick at the tuyeres and 9 inches in the walls above. The tuyeres remain in place 6 inches above the bottom of the hearth, of which the top 9 inches are of magnesia bricks or mass.

Converting in Acid-lined Vessels. — Formerly linings were generally made of quartz bonded with plastic clay. In many places considerable difficulty has been experienced in obtaining a satisfactory homogeneous mixture. The linings in Montana, for example, were formerly made from very refractory dry quartz, bonded with a much less refractory sticky clay. The consequence was that, under the influence of heat, the latter would melt and allow the quartz particles to drop off and mix mechanically with the slag. Hixon reports that the argillaceous quartzite used at Aguas Calientes behaved differently and gave better results on account of its homogeneity. Since that time better results have been obtained in Montana by using sticky, clayey ore with refinery scrap and fine slum as a lining. Great Falls converts regularly 150 tons of matte in each converter of the pear type, which has a diameter of the bottom section of 12 feet. These converters are made in two sections, the lower 6 feet and the upper 4 feet high. The shell is made of $\frac{7}{8}$-inch tank steel. The two sections are jointed by bolting their flanges together.

is dished and half way around the mouth, which is 24 inches in diameter, there is riveted a reinforcing plate 12 inches by $\frac{3}{8}$ inch. The sections are reënforced by angle-iron rings riveted to them. There are several lugs in the lower half of the shell which are

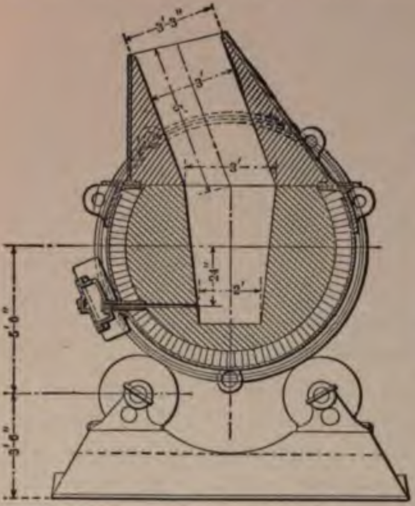

Fig. 61. — Acid-lined Converter.

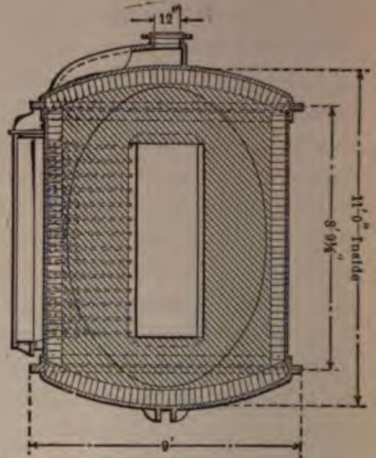

Fig. 62. — Acid-lined Converter.

held by iron bands around the shell. The lining is made about $2\frac{1}{2}$ feet thick at the tuyeres and tapers gradually to a thickness of only 4 inches at the nose.

Rolls and Chili mills are employed for crushing the raw materials when the lining is made of other materials than ore. One part of clay is required for $8\frac{1}{2}$ parts of quartz; the mixture is fed to the Chili mills in the proportion of 40 shovels of quartz to 5 of clay. In winter hot water is used to mix the batch. The material is ground until of the consistency of stiff mud and the quartz pulverized to pea size. When a converter needs relining the nose or the upper half of the converter is removed, by unlocking the key bolts, then the bottom is cooled and cleaned of slag. The lining is pressed in place by a hydraulic or pneumatic tamper, the nose is then cleaned and lined by hand. The converter is then warmed, and the lining baked. The procedure in the barrel converters is essentially the same.

Lining of the Anaconda Converters. — The lining was formerly made of pure white quartz crushed to the size of slack coal in crushers and rolls and afterwards ground in a Chili mill with one shovel of fat, sticky clay to 8, 9 or 10 shovels of quartz, according as the clay seemed to vary in plastic or binding qualities. The clay which was employed contained a somewhat large percentage of alkali earths as well as iron, and only so much of it was used as was necessary to stick the quartz together when moistened and ground in the Chili mill.

Clay Analysis

	Per cent
SiO_2	66.0
Al_2O_3	18.5
Fe	3.1
CaO	2.9
H_2O	8.4
	98.9

The iron of the matte is oxidized in the course of blowing the hot liquid alloy, and combines with the lining to form ferrous-silicate slag. The linings would, therefore, only last a few "blows." In 1900 50 tons of matte could be converted in one vessel, without relining; in 1906 it was possible to convert 150 tons in one converter's campaign owing to the improved methods of blowing such as resulted from the position of the tuyeres and cross section of the converter, the use of good ore lining instead of barren material and an economical use of the converter by blowing heavy charges of white metal after the slagging blow.

Basic-lined converters had been tried ever and anon for many years without good results being obtained. The base used was burned magnesite, the object in using it being to have a converting vessel with a permanent lining, the slag-making constituents being fed in separately and not coming out of the lining. The magnesia conducted away the heat, spalled badly and broke at the tuyeres which were in need of constant punching.

All these difficulties were obviated by working with large vessels. The proportion of heat then absorbed and transmitted by the magnesite from the bath was small, the spalling was less dangerous and the tuyeres did not freeze up easily. The shell of the new basic converter in one instance is 23 feet long and 10 feet in diameter; the cross section after the lining is in place is oval, measuring 6¼ feet high, 7¼ feet wide and 19¾ feet long. The shell of the sides is ¾-inch steel plate, the ends only ¼ inch.

The shell is open all along at the top and secured by tie bars. This permits of the expansion and rising of the lining. It has 32 1¼-inch cast-iron tuyeres along the side and end, is bound by 3 heavy flange rings which run on trunnion wheels, and the main opening for exit of gases and charging of ore is at one end. The slag hole and copper tap are at different levels. The lining is of 9-inch magnesia bricks; 18-inch bricks are used only at the tuyeres. The bottom filling under the magnesia is of fire-clay bricks, 13 inches in the middle and 4 inches at the sides. Magnesia bricks are laid in dry magnesia, in a mass of ground magnesia and tar or of magnesia and linseed oil.*

By the use of the basic lining the old process of relining the converters with silica after a certain number of charges has been eliminated. The process is slow, but cheap on account of the continuous course of the operation.

Copper-refining Furnaces. — Since the province of the refining furnace is one of oxidation, it has necessarily the form of a reverberatory furnace. The functions of the old-fashioned blister furnace, in which roasted matte is treated with the object of recovering the copper as metal and of slagging the iron with silica, are somewhat different from those of the modern refining furnace which either removes, from converter copper, the two or three per cent of iron, bismuth, arsenic, and antimony which it may contain, or else is used for remelting cathodes from the electrolytic refinery. In the latter type of the modern refining furnace the general effect is more neutral; in the blister furnace the atmosphere is more actively oxidizing. Yet, even in the modern refining furnace some oxidation is effected by the introduction of air through pipes or by poling. The hearth of the old blister furnace naturally demanded a bottom and walls of silica. It was found first that the fire-clay brick made in the early stages of copper smelting (1840 to 1880) did not last as long as silica which was originally used in the form of sand on the bottom and of brick on the side walls. The cuprous oxide and the copper, which dropped to the bottom during the progress of the oxidizing of the matte and during the reaction of the cuprous oxide and sulphide, entered into combination with the silica, forming cuprous silicate, which knit together and agglomerated the surface of the sand bottom. The sand was added during the process to slag the ferrous oxide. The silica and ferrous silicate were less vicious in their attacks on the silica brick of the bath walls than on fire-clay brick, because there were always some bases in the fire-clay brick which would attempt to combine with the silica in the free or slag form, at the expense of the life of the brick. The silica materials were less fusible than the fire-clay bricks. This holds true to-day only to a certain degree, for the first-class fire-clay bricks now on the market are amply able to withstand the temperature produced in refining furnaces. They are more safely used in matting than in refining furnaces.

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* Peters, "Practice of Copper Smelting," pp. 516, 518, 519.

In all processes in which metals are produced the hearth bottom must be impervious to the metal. Copper soaks into silica and forms cuprous silicate slag on the surface but it does not eat holes through the hearth. Fire-clay bricks, by reason of their physical defect of expanding but little when fired, do not make a tight bottom. The old blister practice was transferred to the modern refining furnace and has made good. The hearth bottom (now of silica brick) is still held firm by the formation on the surface of cuprous silicate; the inverted arch bottom is made preferably of this brick on account of its regular and even expansion and the silica side walls and roof of silica brick give satisfactory results. The use of magnesia is, nevertheless, to be advocated for the hearth walls, at least, since in the modern furnace whatever slag may be formed will contain principally oxides of metals and metalloids.

Nothing can illustrate the qualities of the silica lining better than the experience of Mr. Edwin M. Clark.* Mr. Clark's problem was to smelt silicious zinc and copper bearing pyritic concentrate. He roasted them in a homemade furnace, 50 feet by 14 feet, made of stone and adobes. These adobes are made from mud, generally carrying some alkali, which is pugged and moulded by hand and dried for a week in the hot sun of the torrid zone. They are then firm and develop some incipient vitrification after being used in flue and furnace walls. The roasted ore was smelted in a wood-fired reverberatory furnace with a hearth 7 feet by 13 feet and a bath 12 inches deep. The bricks in the whole of the roof, in the lining of the walls of the hearth and fire box and in the floor of the hearth were of silica. These were made at the furnace (in Mexico). Two pots of dry crushed clay were mixed with five pots of pulverized quartz, and pugged with sufficient water to make the mixture of mortar consistency. The mass was dried until sufficiently stiff to mould into brick in a hand press. These were then dried in the open air and burned in a kiln made of red bricks. The foundation of the hearth was built up from the floor with 12 inches of crushed rock and clay followed by 6 inches of sand, 4½ inches of red brick and 3 inches of brasque, composed of clay, charcoal and sand, upon which the inverted arch of silica brick was laid. The outside of the lining of the walls was made of red brick.

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* *Min. and Sci. Press*, April 23, 1910.

Even with this homemade silica brick the hearth more than justified its form and manner of construction. Any one who has worked with fire-clay brick has realized the difficulty of making a tight inverted arch to hold metal, and the care demanded in holding a wide-arched furnace roof made of this material, when it has been subjected to high or to changing temperatures. It is often advisable to scatter ground quartzite on the silica bottom and allow the first copper or cuprous oxide to agglomerate with it into a slag which makes the whole bottom tight although it does not stop the "wandering" of copper through the silica brick. Time will be saved if the bottom be covered with copper scale or with partly oxidized copper scrap, produced in wire mills and other factories.

In constructing a modern refining furnace the difference in objective must guide the mason or engineer who may be under the influence of the giant matting reverberatory. The refining furnace handles relatively small quantities of heavy metal; it is, therefore, made with a deep hearth of small area. The metal is a good conductor of heat, it permeates the bottom, and tends to make its escape through pores and small holes as long as it is hot enough to run; the hearth is, accordingly, often air-cooled by being built on cast-iron plates, which rest on masonry columns. If it be built up solid from the floor it will probably absorb a considerable quantity of copper before it finishes its life and rob the company of its just interest.

When built on brick pillars, these are capped by steel plates on which the cast-iron hearth plates, 1¼ inches thick, rest. The hearth bottom is made of two flat inverted arches, the lower of fire-clay bricks and the upper of silica bricks; each is 9 inches thick. These arches rest on brasque or, more often, red bricks,

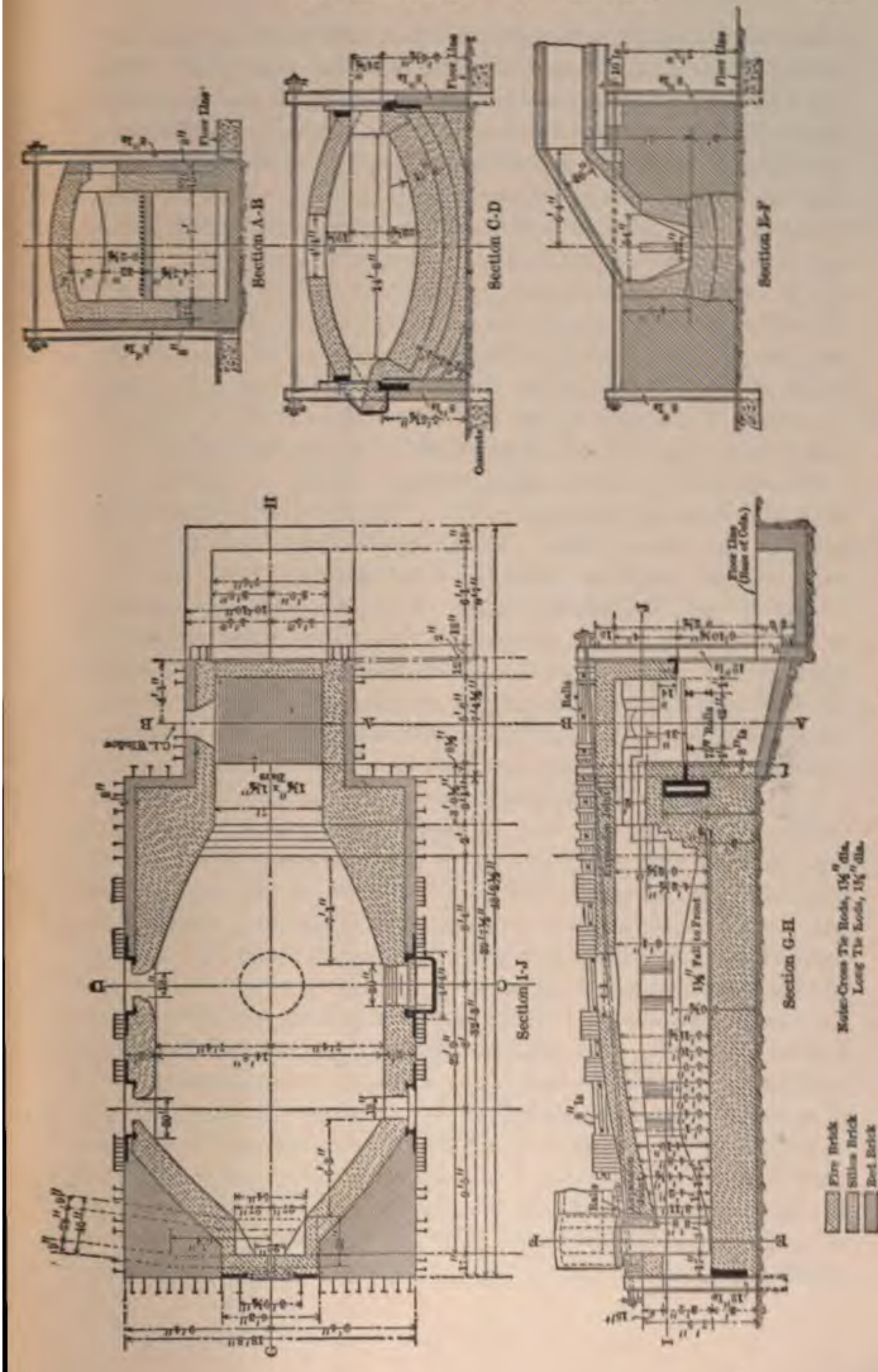


FIG. 63. — Copper-refining Furnace at Anaconda.

except at the center where the fire-clay bricks arch touches the plates. The roof is a silica-brick arch, 9 inches or 12 inches thick. The walls are generally lined with magnesia up to the slag level. This lining may be 9 inches when the total thickness is 18 inches. The outside brick is a second-class fire-clay brick. Above the magnesia bricks, silica or fire-clay bricks may be used. The whole is held by buckstaves (preferably channel irons) and the bars which may be controlled by turnbuckles or, more often, screw nuts. The size of furnaces varies greatly. Anaconda's anode furnaces are 26 feet by 14 feet 8 inches clear in longest hearth dimensions but the sides narrow to 7 feet at the fire box and to 54 inches at the bridge wall. The area of the fire box is 7 feet 6 inches by 5 feet 6 inches. The height of the roof above the hearth is 6 feet 2½ inches at the fire bridge to 3 feet 8 inches at the flue bridge.

The method of setting silica bricks is similar to the practice employed in laying magnesia bricks. Wherever possible they are laid dry and skin to skin. The inverted arches are "grouted" with crushed quartzite, silicious ore or other material, which is "sweated" into the hearth bottom before the furnace is charged at the beginning of its campaign. Sometimes scrap copper or even refinery slag is thrown over the floor and sintered with the loose silicious material into a tight covering for the floor. Everything is done with a view to minimize the chances of the hot copper metal working its way through the hearth and ultimately making a tap hole which will suddenly grow large enough to empty the molten bath before this may be plugged. The slag bottom, the tight inverted arch which knits more closely together as it expands gradually and regularly under the influence of the heat of the bath, and the use in many cases of the cooling vault combine to prevent the "sickern" or trickle of metal through the hearth. Of course the absorption of copper by the silica goes on continually; the deeper the hearth bottom and foundation, the more metal will be absorbed. It is also true that, while the air-cooled vault enables the operator to detect any leakage, it sometimes is more of a danger than a safeguard to the life of the furnace. Unless there is a continuous flow of air under the vault, and unless the floor about it is kept clean of slag and scrap, the vault is liable to act as an insulator, and help the copper in its efforts to percolate through the hearth bottom. The silica used in the bottom, whether to grout the silica bricks, or as mass replacing the bricks, should be as nearly pure as ordinary quartzite. Even some sandstones may not be used since their content in bases is sufficiently high to soften the silica at high temperatures. The second important essential, however, is that the material should be in the form of splinter grain — neither round like sand, nor too fine like dust. Quartzites and silicious ores nearly always grind to sufficiently satisfactory rough splintery and heterogeneous grain to make a good bottom.

CHAPTER VIII

REFRACTORIES USED IN THE METALLURGY OF LEAD AND SILVER AND IN GENERAL METALLURGICAL PRACTICE

It is not so much in the smelting of ores as in the refining of base bullion and alloys that a particular knowledge of the properties of refractories is demanded of the intelligent operator. The temperatures employed in roasting and smelting are not high enough, nor the slags and metal combinations sufficiently corrosive, to demand special qualities in refractory materials. In the process of refining, on the other hand, the operator has to deal with metallic slags of a type which are particularly difficult, in that they will attack viciously any acid lining, by forming silicates with its ingredients, and yet will change their whole character and corrode a basic lining by acting in the rôle of acids. Some of the metals accompanying lead in ores, such as antimony and bismuth, are particularly difficult to manage. Accordingly metallurgists, smelting antimony or its ores, safeguard the life of their furnace by lining it with chromite—a neutral and unassailable refractory. Lead itself acts as a base in the oxidized form. On occasions it will become acid and form plumbates with alkaline earths, but these are unstable at high temperatures, so that a magnesia lining, for instance, is but little affected by molten litharge. In the roasting of lead ores similar conditions to those existing in roasting copper ores prevail. The long hand roaster does not require high temperatures. If the ore is slag-roasted the hearth next to the fire bridge is made of first-class fire-clay bricks. The rest of the hearth, the roof, walls and the fire box are generally built of a second quality fire-clay brick. In kilns and stalls, old bats may be used with advantage. Brueckner's and other rotary calciners used in lead smelting are lined to a depth of 11½ inches with fire-clay brick.

In the mechanical roasting furnaces, whether equipped with moving hearth, as the Godfrey, or with stationary hearth and

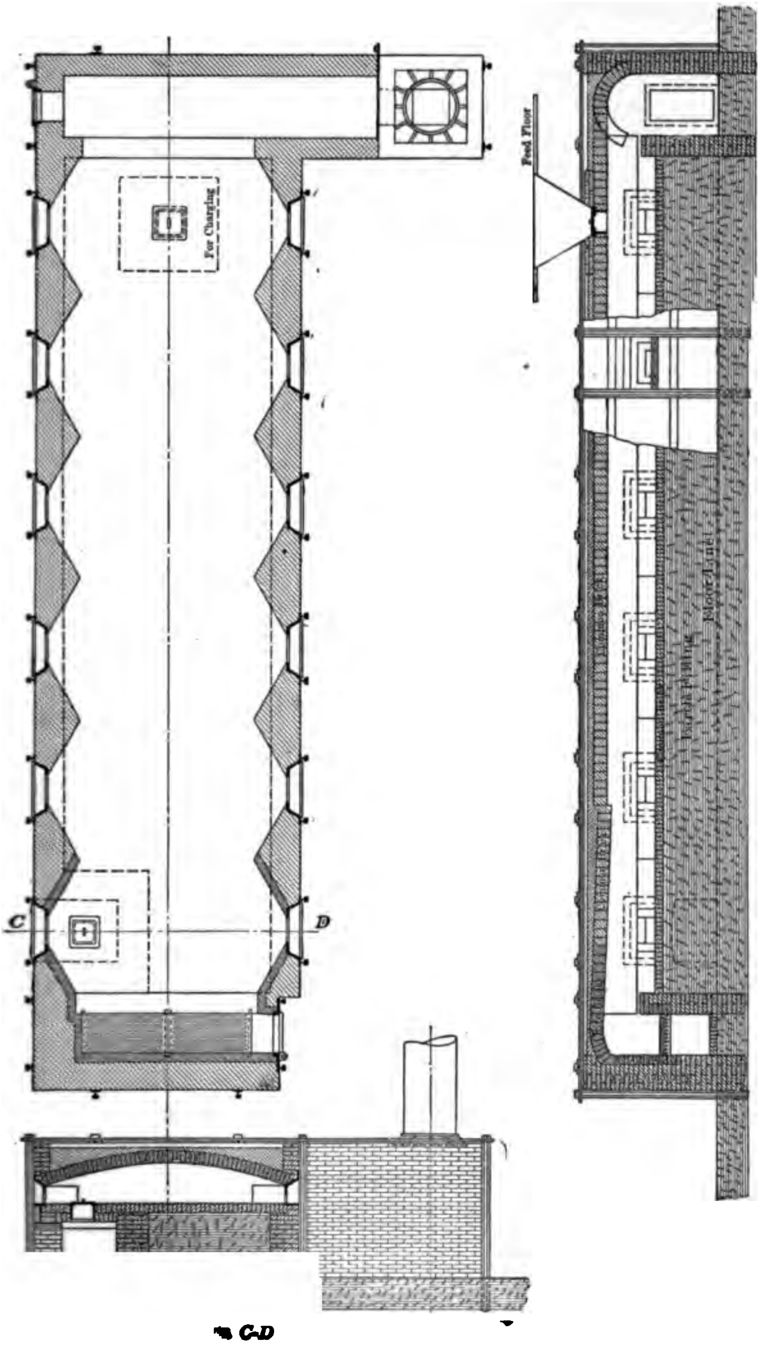
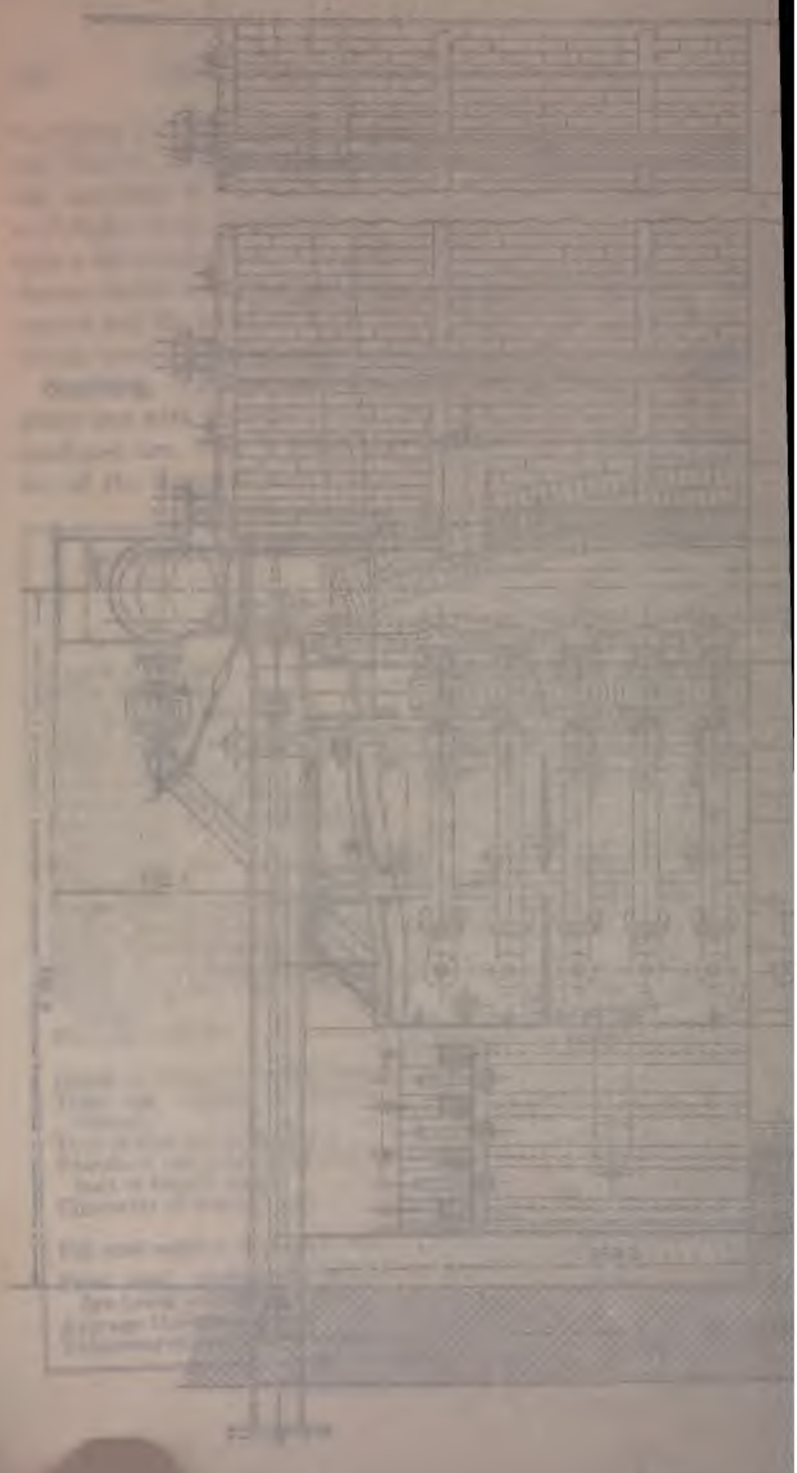
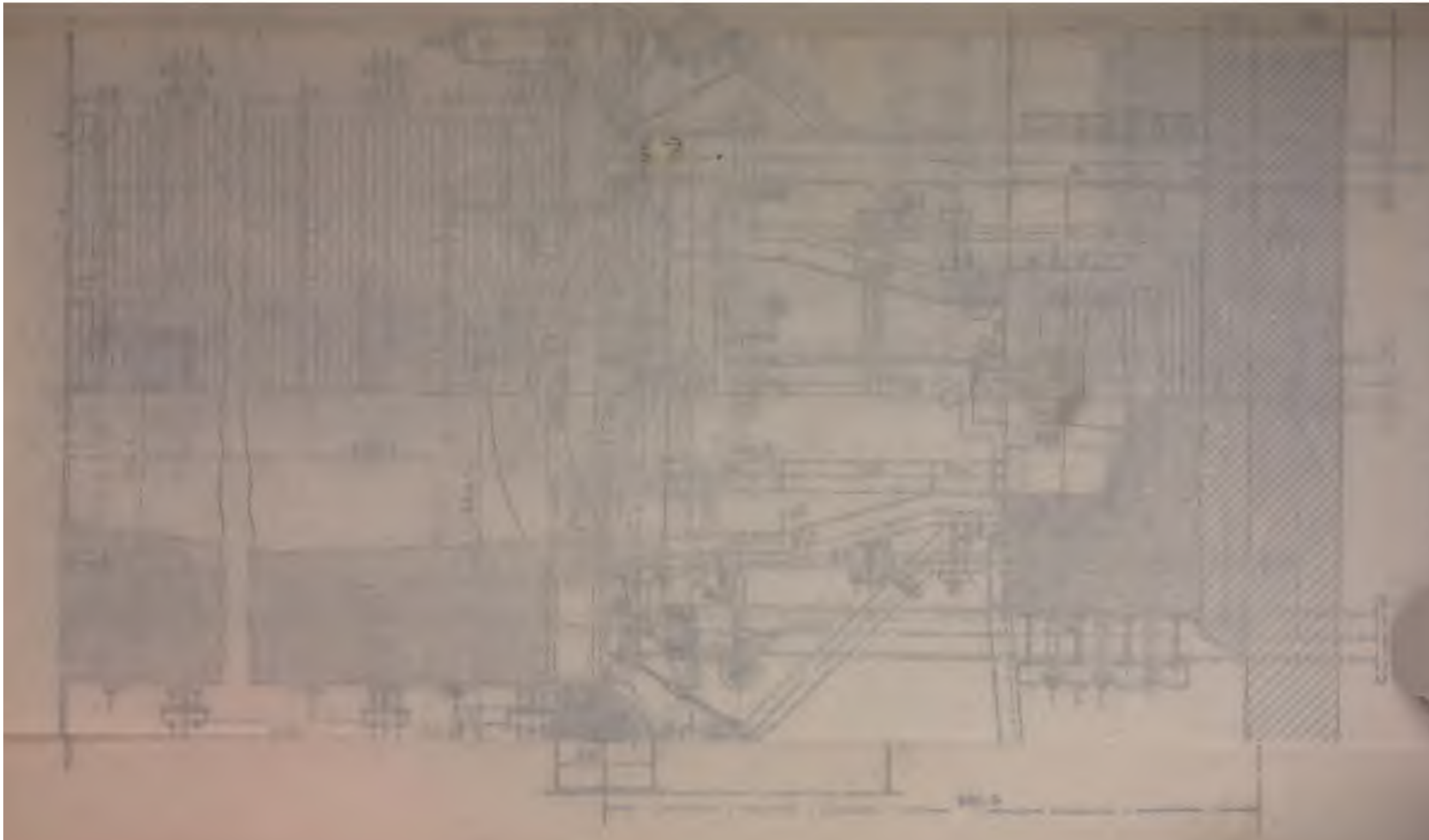


FIG. 64. — Long Hand Roaster.





silica present; as a rule, with 60 per cent bases. The latter consist of lime and ferrous oxide in proportions of 1:2 and 2:3, or, in rare cases, 1:4. The silica, in some instances, is as high as 35 per cent. The formation temperature of these slags is not particularly low, but the flowing temperature is essentially so; accordingly, the lining is neither subjected to high temperatures nor to excessive corrosive action. The lining is, indeed, not exposed to the attacks of the slag proper, since the 4 feet of the furnace shaft directly above the crucible are jacketed by means of a number of bosh vertical water jackets, generally of cast iron, 4 feet high and 18 inches wide; each has, directly below the boshed part, an annular opening, 3 inches in diameter, to hold a tuyere. The most aggressive attacks on the lining above the jackets are made by sulphide of lead or mixed sulphides which frit against the lining and break it down as the column descends. Zinc, in the form of blende, or as oxide, resulting from volatilization in the lower parts of the furnace, also slags the lining.

The crucible wears out more quickly than should be expected from the temperature and character of the metal in it. Yet it is rarely free of lead; and on the surface of the lead there are always sulphides, oxysulphides and arsenides of this metal, along with speiss and matte. Some of these alloys attack the lining quickly, acting both as acids with the bases in fire-clay brick and as bases with the acids in the lining. Since the basic action is most active, the lining may not be of acid material. Silica and quartzite bricks are out of the question; highly aluminous fire-clay bricks are better, but are excelled by bauxite, magnesia and chrome bricks. Magnesia is the most economical in the long run and is now used very generally as a lining in the crucible. The smeltery at Laurium is fortunate in its situation, near the source of supplies of magnesite and chromite, and the management has enjoyed first-rate opportunities of testing these refractory materials.

Its blast furnace is 20 feet high from the top of the crucible to the charging flow and 17 feet 6 inches by 4 feet clear at the crucible. The bottom of the crucible is 2 feet thick above the bottom furnace plate which rests on a concrete foundation. The walls of the crucible are 2 feet 6 inches thick. The floor is an inverted arch. The bottom and walls are lined inside with 6 inches of magnesia brick; next to this is a 9-inch course of fire brick; the outside 11 inches are of brasque. The whole is securely bound by I-beams in a steel shell. This magnesia lining consists of bricks made from 3 parts of calcined magnesia and 4 parts of chromite. This mixture is ground, tempered, pugged and moulded under a high pressure and burned at a temperature of 1600° C. They are more refractory in that the brick is more neutral than straight magnesia and are less inclined to form alkaline antimonates, plumbates and other salts with the lead and its impurities.

The siphon, tap and spout are also lined with magnesia. The cast-iron spout is covered with a full-brick thickness of magnesia.

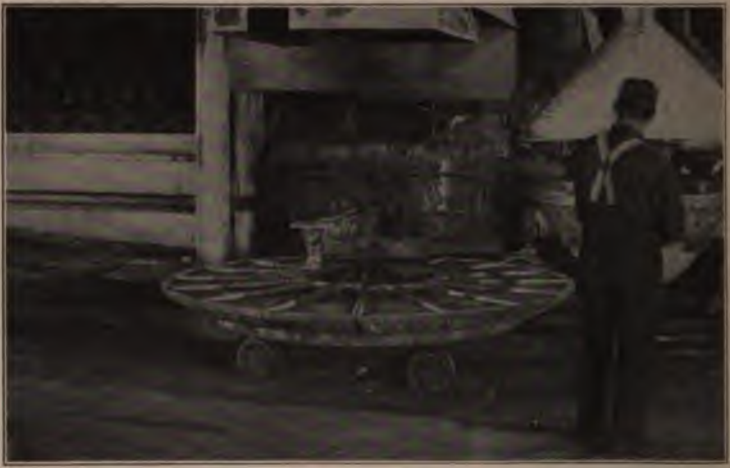


Fig. 66. — Settler with Slag Pot and Kilker Matte-tapping Car.

The shaft is supported in the usual way. Four hollow cast-iron columns, 8 inches in diameter, of metal 1 inch thick, with capital and base carrying a mantle consisting of 3 I-beams bolted together, support a plain flangeless cast-iron plate, on which the brickwork is built. Sometimes the I-beams are replaced by a strong brick arch springing from heavy cast-iron skewbacks resting on the columns. The shaft walls are often of fire-clay brick throughout the thickness of 4 full bricks. More often the inside lining of one or two full bricks is of first-class fire-clay bricks while the rest is of ordinary red brick. If the gases are taken away below the charging floor, the flue must be lined with $4\frac{1}{2}$ inches of fire-clay brick. If the shaft continues above the charging floor, this part is lined with 9 inches of fire-clay brick, but the downtake need not be protected. The settler is lined with fire-clay bricks, or with magnesia bricks to a thickness of 9 inches. Its lining is never greatly corroded, because the settler generally becomes "full" or "frozen" and is removed after a campaign of 7 to 15 days.

The liquating hearths in which the lead bullion is sometimes separated from its copper content are made of second-class fire-clay brick. More care is demanded in making the hearth of the softening furnaces in which the drosses are removed, and the tin, arsenic and antimony separated by oxidation from the bullion. These oxides cut very quickly into fire-clay bricks. Formerly this was protected by being cooled by means of water jackets. Now magnesia is used as an inside lining, or the wall, up to the slag line, may be built solidly of it. The floor of the hearth has an upper layer of 9 inches of magnesia bricks. Jackets are often used and extend from the hearth bottom to the slag line.

The bricks should be laid in thick-tar and ground-magnesia mortar, which must be kept hot and worked rapidly. Sometimes the roof may be made of fire-clay brick (highly aluminous), especially in cases where the dross and abstrich may be contaminated with roof drippings of silicates of lead, bismuth and antimony. This is the practice when these drosses are resmelted at the plant.

If a pure abstrich is desired it is wise to make the roof of magnesia. On account of the liquidity of the bath it is not admissible to lay the magnesia bricks skin to skin without the use of mortar. The magnesia floor of the hearth may in almost all cases be replaced by good fire-clay bricks. In this case it is well, although not necessary, to insert a buffer layer of chromite bricks between the floor and the magnesia sides. The sides are generally made 2 or 2½ bricks thick. The corrosive slags of the metal oxides on the top of the bath will eat the hot magnesia until they reach a point where the cooling action of the outside water jacket is felt. The lining from this point to the jacket should last for years.

The reverberatory furnaces, used in the process of smelting lead ores by the roast and reaction process, and the hearths, used at Bleiburg and elsewhere, work at such low temperatures that no specially good fire brick is needed. In the construction of both reverberatory and hearth, it is usual to use fire-clay-brick lining inside a red-brick wall. The hearth bottom should be made impervious to the lead by sweating litharge or clay on it before the campaign begins.

The ordinary practice in the metallurgy of argentiferous lead is to liquate the base bullion, then to soften and desilverize it. The desilverization may be done by the Parkes or the electrolytic processes. In the former zinc, to the amount of 1.5 per cent of the bullion, is added to the metal which has been melted in a cast-iron kettle holding 50 tons. These cast-iron kettles have a long life, if cast carefully and of good iron. The zinc alloys with the silver and the resulting zinc-silver-lead scums obtained on cooling the bath are liquated to separate the liquid part of the lead from the dry scum. This is now heated in a retort to which a small condenser is attached. The zinc distils over and is recovered in the condenser. The retort is generally of graphite and is held inside a fire-brick box which may be tilted. The heat is supplied by gas, oil or coal. The condenser is of fire clay, with a tap for the zinc. The lead-silver alloy, remaining behind in the retort, is cupelled on the hearth; the lead is oxidized and drawn off and the silver, with gold and other precious metals, "blicks" in the form of doré silver on the hearth. The silver alloy is then parted to recover precious metals.

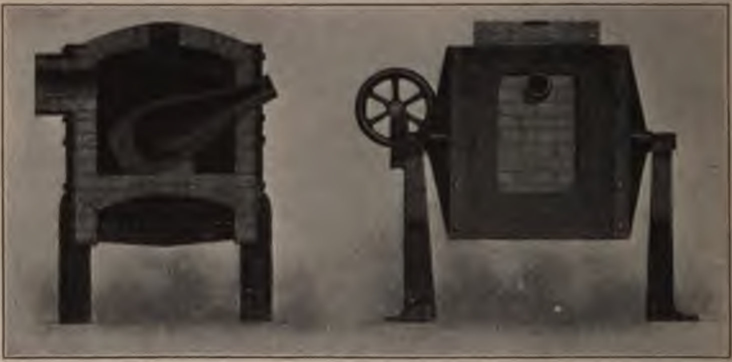


FIG. 67. — Zinc Distilling Retort (Parkes Process).

Cupelling Furnaces and Tests. — Bone ash, marl, cement, cast iron, magnesite and chromite have all been used in cupellation. The disadvantage of the use of the first three named is that they make the work intermittent. After each run the hearth must

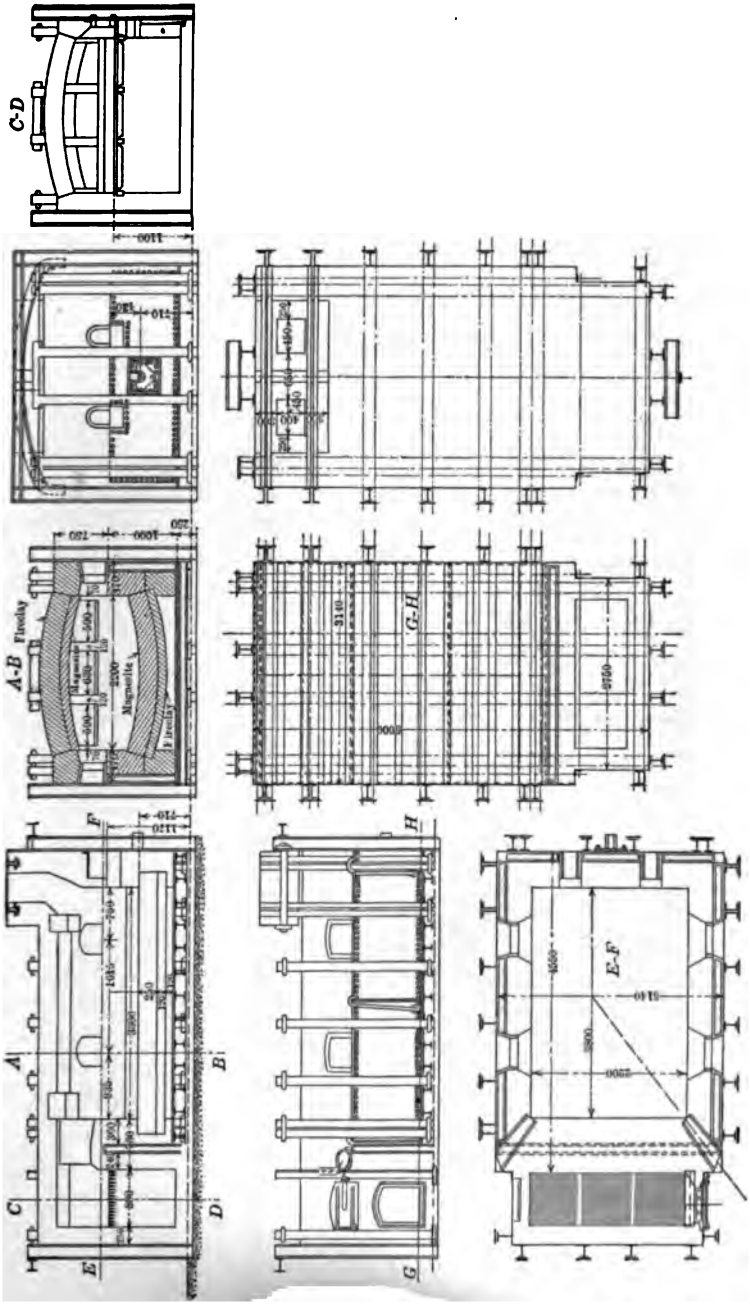


FIG. 68. — Large Silver Cupelling and Refining Furnace.

be torn out and resmelted in the blast furnace to remove the lead and silver absorbed. This is expensive since the hearth mass is refractory and requires high temperature to decompose it. Cast-iron cracks under the strains of heating and cooling but resists the action of the oxides fairly well.

Chromite is not as satisfactory as magnesia which is now almost entirely employed, both in the form of bricks and of mass. The small test, holding five tons and running a campaign of six months, may possibly give way to a large magnesia-lined-reverberatory bath furnace. When once the surface of the lead, of the bullion charge, is converted by an air blast into a thin layer of oxide, the process of feeding pig bullion may be continued regularly and continuously from the fire-box end. The pigs of alloy swim toward the slag notch, at the far end; their silver is absorbed by the bath and a stream of silver-free antimony-oxide slag, tin slag and later litharge made by oxidizing the impure base bullion, first of all by means of the oxygen of the thin scum of litharge on the bath, and then by the blast itself, runs continuously over the magnesia block-notch. This may be gradually cut down, when the bath becomes heavily enriched with silver. The feeding of the pigs on to the bath then stops and the bath is concentrated by drawing off as much litharge as is reasonably silver free. The rich silver bullion which remains behind should then be tapped and transferred to a smaller test and cupelled. (See Fig. 68.)

The German cupelling hearths, made, since the time of Agricola, with a movable roof, are circular or oval, with an attached fire box of rectangular cross section. In the case of the oval hearth the outside dimensions form a rectangle with the breast on the middle of the short side farthest from the fire. In the round hearths the outside form is generally round. The shell of the hearth is of second-class fire-clay brick. The foundation of the bottom of the hearth is an iron plate upon which a layer of brick was set on edge. Ducts are made in various places to permit of the escape of gases from the hearth which is tamped by hand, and consists of two beds. The lower of these is permanent and is made of marl, of marl and clay or of clay and sand. Above this the real cupelling hearth is carefully laid with a thickness of from 6 to 12 inches. It is made of marl and clay, cement or bone ash.

The American Test has a hearth movable on a buggy, with jackscrews to permit of raising or lowering it. It is relatively small

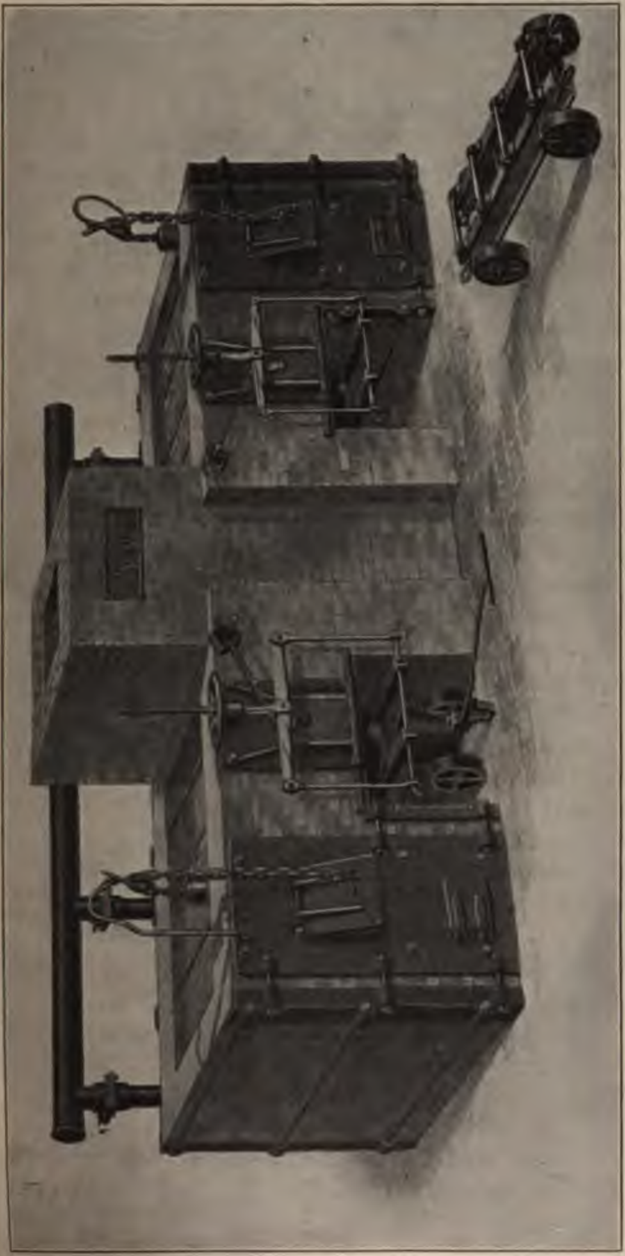


FIG. 69. — American Test Furnace.

(about 6 feet by 4 feet over all) and is made of magnesia tamped inside the steel shell. Sometimes the bottom is made of magnesia brick; at times both bottom and sides are laid with this material instead of with magnesia mass.

In the metallurgy of antimony the reverberatory furnace which reduces the oxide to the metal should have bottom, hearth and sides of chromite. The roof and side above the bath level may be made of good magnesia. Fire clay sweats in the antimony vapors, and the antimony aluminate and silicate falling into the bath are liable to make it impure. Silica is somewhat more satisfactory but magnesia is the best and in the long run most economical for the roof and the upper part of the side walls. Chromite cannot be excelled for the lining of the hearth. The foundation on which the bottom of chromite rests, and the outside brick of the sides, may be of fire clay.

The volatilizing shaft furnace in the French process is lined with good fire-clay bricks. The pipes through which the antimony ore and ground coke are fed may be made of fire clay or cast iron.* It is possible that some of the troubles, incident to treating tin and tin ores in the old type of fire-clay brick-lined reverberatory, may disappear with the use of a jacketed magnesia or chrome lining.

Refractory Materials in Flues, Dust Chambers and Stacks. — Flues and dust chambers are generally framed of structural steel built in by walls of brick. In places where wood is inexpensive the side stay beams may be replaced by square wooden posts held by steel tie bars above and firmly imbedded at the bottom. In small flues the roof may be made flat, level or inclined, and is then carried on a network of small T-beams. If of large section the roof is formed by jack arches sprung between I-beams. The lower surface of the steel may remain uncovered in dry parts of the flue, but must be covered with an acidproof paint wherever moisture is liable to attack it.

Bricks are most generally used in the walls and roof. Concrete, in the form of hollow and solid blocks, and reënforced with expanded metal, Monier network or iron bars, has invariably failed. These materials disrupt most rapidly in damp climates, and the gases from lead furnaces attack more actively than those from copper furnaces. This is due to the fact that the former are cooler and deposit more moisture and aqueous acids. If the flue is protected from outside elements by a superimposed wooden shed, it will last much longer, even though it be attacked on the inside by aqueous acids. Steel flues, ellipsoidal and oval, are better than the concrete, but they are found less economical than brick. Flues of natural rock have been used to a great extent in past decades and still survive in England and Ireland. They are, without doubt, the strongest and most successful of all flues and chamber materials, but the masons' and rock cutters' wages are too high in America to permit of their general application.

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* See articles on "Antimony," *Mineral In*

These freestones were pointed with a mortar of mud, or sand and clay. In one plant in Europe the walls of the flue were built only one-half brick thick; they were made firm by interleaving strips of iron running zig-zag from the bottom to the top of the wall, following always the joints, and by strongly buttressing at regular intervals. The whole of the interior brickwork and iron roof was painted with mortar made of hot tar and sand. This flue proved very effective in resisting and cooling wet gases from lead furnaces. A glazed tile roof proved durable, and heat and acid resistant, but could not be made sufficiently air-tight, and required a large network of angle iron to hold it.

Baffle rods and plates may be made of iron and suspended in the gases to precipitate the dust and fume contained in the gases. These are protected from the attack of the gases by the coating of fume or dust which is immediately deposited. The bags through which gases are filtered may be made of wool, duck or of asbestic cloth. Efforts have been made to make the duck and woolen bags fire-proof by treating them with various mixtures of water glass, boracic acid, borax, salammoniac and other fire-resisting paints. These did not prove of much avail and, at present, operating temperatures are generally so low at the bag house that such treatment is not necessary. The asbestos thread bag of Fiechter has proved successful and desirable both in industrial factories and in metallurgical works. A number of threads, suspended from a ring, close together form the bag. This is shaken at regular intervals, and the dust which falls below may be automatically discharged outside the chamber by a screw conveyor. These bags of Fiechter are especially to be recommended in handling hot gases.

The stacks are made of second-class fire clay or good red-brick clay in all the larger works and lined with acidproof blocks laid resisting mortar such as water glass and asbestos.

The chimney of the Great Falls plant * is 506 feet high and has an inside diameter of 50 feet. The base of the stack is formed of slag concrete in proportions 1: 3: 5; viz.: 5200 barrels of cement; 2000 yards sand; and 4000 cubic yards crushed slag.

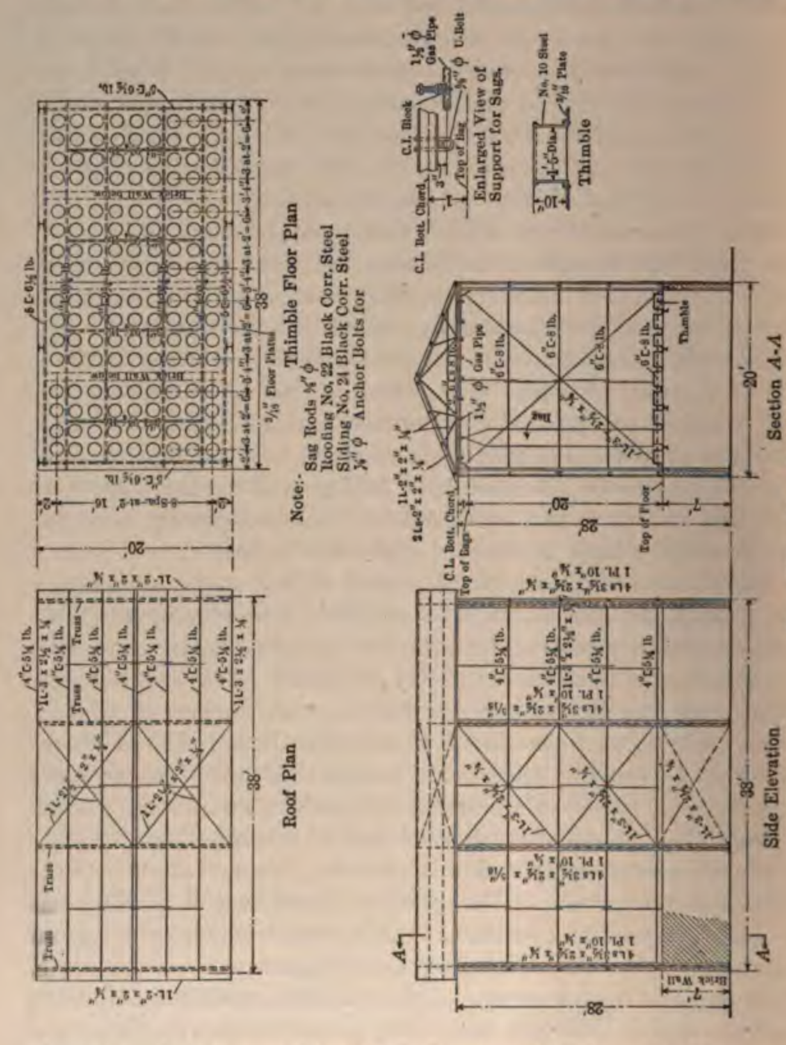

FIG. 70. — Bag House.

Special bricks of good clay, shown in the illustration, were made on the spot. The chimney proper required 13,000 tons of radial

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* Peters, "Practice of Copper Smelting," pp. 588, 589.

brick, 3075 barrels Portland cement, 5225 barrels of lime and 4180 cubic yards of sand.

Factory Chimneys.*— Artificial brick, natural rock, concrete and iron are used in the construction of chimneys. The brick, rock and concrete must all fill certain conditions.

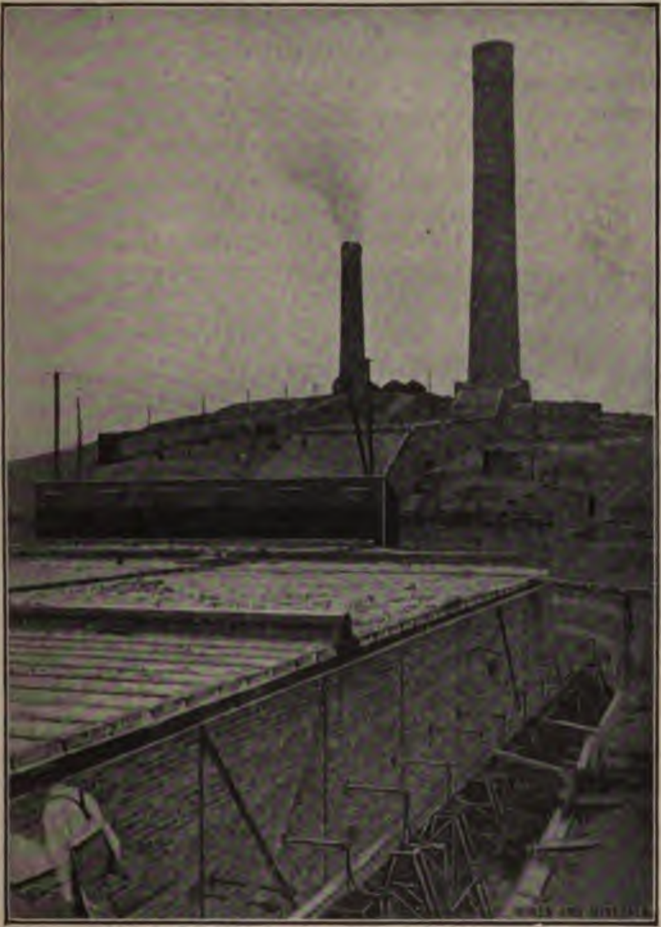

FIG. 71. — Great Falls Condensing System.

(1) The specific gravity of the material should be as high as possible.

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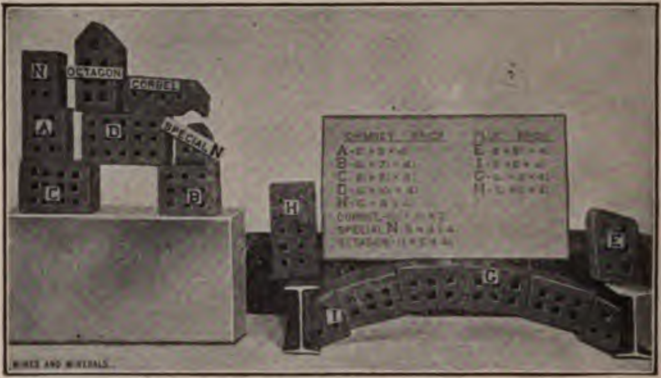
* For general discussion of chimneys see "Industrial Furnaces," by Damour eau, published by the McGraw-Hill Book Company.

(2) The capacity for absorption of moisture and the permeability of air and gas should be low; the modulus of heat conductivity must be as small as possible. Low factors in these three properties contribute to the production of a good draft.

(3) The materials must be refractory to the highest degree comparable with moderate cost. They must be resistant to the influences both of weather, such as heat and cold, and of chemical influences such as develop in passing fire and acid gases past the argillaceous, calcareous or silicious materials composing the chimney. Moisture contained in the brick disrupts them when freezing; frost will likewise cause silicious rocks and bricks to crack owing principally to the granules of contained clay which have a capacity for absorption different from silica.



MINES AND MINERALS

Fig. 72. — Bricks used in the Stack of the Great Falls Smeltery.

Chemical influences include the hydration and superoxidation, of constituents, oxidation of the iron and its oxides in the material by means of air and carbon dioxide, and by the action of CO when carbon is deposited. Acid gases attack all unprotected chimney materials and are especially severe on concrete.

(4) The material, brick or stone, should have a certain degree of tenacity.

(5) Natural rocks should not be used above the foundations and pedestal of the stack. Granite, basalt and sandstone may be used in the foundations. The rest of the stack should be of red bricks, clinker, vitrified bricks, fire bricks and refractory bricks.

The ordinary red bricks made from loam and sand should not absorb more than 16 per cent of their weight of water, should have a sharp cleavage and ring when struck. Since these bricks are generally very porous they are not well suited to the chimney itself.

The clinker bricks are burned well and at a higher temperature than the red bricks. They vitrify on burning, are harder and more durable and have a smaller absorption capacity than the red bricks.

The radial chimney bricks proper should be made from a fat, arenaceous clay. Sometimes they are made hollow but these are seldom as satisfactory as the solid bricks; the lower first cost and small expense incurred in transportation are in their favor.

The outside of chimneys may be of face bricks. The denser or less porous these are, the less heat they will conduct and the better they will answer their purpose.

Concrete is often unsatisfactory and disrupts under the influence of fire or hot acid gases and should be used with circumspection. A second-grade fire-clay brick may be almost generally used in all factory chimneys provided it is of a kind to fill the requirements considered above.

The joints should not be made more than ¼ inch thick. The mortars are made of water with sand and clay (mud), or with lime and sand; with lime, sand and mud, with cement, sand and plastic fire clay which often has admixed grog. Particular attention should be paid to the water used; it should be pure and free from mineral and alkali salts. The quantity of water varies from 8 to 22 per cent in weight of the sum of the materials used in the mortar. The sand should be sharp and if possible crystalline and with grains of heterogeneous form and size. The lime obtained by slaking the burned limestone is named either fat or lean according to the quantity of silica it contains. The lime mortars contain the ratio of lime to sand as 1:2 or 1:3 or 1:4. The water added should make the mixture pasty. Lime mortar is porous, heat conducting and permeable to water and gases. It contracts on heating and is not at all adapted to any structures exposed to even a small degree of heat.

The cement mortar is made in the proportions of 1 cement to 2 or 3 of sand. Neither this nor lime-cement-sand mortar is resistant to acid or fire gases.

The most satisfactory bonds are the loam or mud and sand, and the fire-clay mortar made of ground chamotte and plastic clay, which is thoroughly pugged with water.

The Action of Gases Containing Carbon Monoxide on Brick.— Carbon monoxide splits up into C and CO_2 ($2 \cdot CO = C + CO_2$) in the presence of free iron or free metals of the iron group. Carbon monoxide oxidizes iron indirectly. The iron causes deposition of carbon and formation of CO_2 which oxidizes iron to FeO. This reaction proceeds until complete equilibrium between all five substances is obtained, which can only occur for a single partial pressure of each of the two gases and a single total pressure on both gases. If the partial pressures of CO and CO_2 in the furnace, taken together, are greater than this single critical pressure, then oxidation of the iron can take place with deposition of carbon; if the pressures are less, carbon can be deposited but no iron oxidized.

The value of this critical equilibrium pressure varies only with the temperature, which is as follows:

At 500° C..........	15 mm.	At 700° C........	305 mm.
550° C..........	35 mm.	750° C........	535 mm.
600° C..........	70 mm.	800° C........	800 mm.
650° C..........	145 mm.		

The partial pressures of CO and CO_2, being seldom less than 250 mm., reduction may take place down to 690° C.[*]

Fireproof Wood.—A process for making timber fireproof consists in subjecting carefully selected timber to saturation, evaporation, impregnation with chemical salts and drying. The timber is first steeped in water and thoroughly saturated to rid it of sap and fermenting substance; this absorbed water is then driven out by drying. The wood is then placed in cylinders and treated with sulphates and phosphates of ammonia and other mixtures, the composition of which is controlled by patents. These solutions are forced in under a pressure of 80 to 120 pounds to the square inch, the pressure used depending on the kind of timber and the character of the grain. The quantity of solution absorbed is generally equal to the weight of the timber.

It is then dried in kilns. The solution should permeate the whole body of the timber and not only the outside of the joists, planks and posts.

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[*] *Electrochem. and Met. Industry*, December, 1905, p. 475.

Wood has been used in the construction of chambers and flues built at some distance from the furnace. Such a structure was built and operated with fair success at the smeltery at Call in the Eiffel, Germany. The wood was not prepared to resist fire in any way and was ultimately destroyed.

CHAPTER IX

THE REFRACTORIES USED IN THE CHEMICAL AND ELECTRO-METALLURGICAL INDUSTRIES

THE development of the chemical and metallurgical industries is due in no small measure to the help and the coöperation of manufacturers of acid-resisting and high-temperature-proof ware. Yet but few absolutely new materials have been offered to these industries; the standard refractories have, rather, been adapted to serve the new purposes and to meet the new developments. These refractory materials may be divided into (1) the clay refractories, such as porcelain and acidproof brick, tile and pottery; (2) the silica refractories, such as quartz and quartzose materials, glass, etc.; (3) the alumina-silica refractories, such as alundum; (4) the neutral refractories, as carborundum, crystolon and siloxicon; and (5) the basic refractories, as lime, magnesia, etc.

Porcelain. — Porcelain is the translucent product of burning kaolin with feldspar and quartz at such a high temperature that it vitrifies homogeneously, producing a semi-transparent slag of alumina silicate. The kaolin lends itself to delicate throwing, moulding and decoration, hence the shapes produced by the porcelain works of Dresden and Sèvres and the earlier products of Chinese craft are especially beautiful among clay products. The vitrified or highly burned kaolin in the form of capsules, retorts, etc., is almost completely acidproof and in the form of the smaller vessels, at least, is also fire and heat resisting. Hard porcelain is most generally known in its glazed form. The glaze is a lead-free salt which runs only at a high temperature.

Soft porcelain is made from a kaolin which may contain small quantities of bases. This fuses at a lower temperature than that at which the hard porcelain is burned. It is a much inferior ware and may be decorated for some purpose with a lead-bearing glaze. It is the hard porcelain par excellence which is really acid resisting. It is familiar to chemists in the form of capsules and small crucibles with the mark of Dresden or Berlin. Soft porcelain and earthenware is often used as acid-resisting ware. It is, however, in reality the glaze which is acidproof. This increases the power of resistance to acids of the groundware because it makes it less pervious. However, the ware is, as a rule, required to stand greater physical than chemical strain, and should, above all, resist high and sudden changes of temperature. The temperature of sintering or vitrification should be considerably below that of melting or softening; the contraction in drying and burning should be small and the clay or material used should be sufficiently plastic. It is almost invariably necessary to use some ground bats or broken vessels as grog with the fresh clay to decrease the shrinkage. In the preparation of ordinary acidproof earthenware it is often advisable to add some mineral or salt to the clay to reduce its temperature of sintering or vitrification. Feldspar is generally added, but in most cases it is not necessary or even advisable to maintain a white body so that some mineral containing considerable feldspar may be used, such as phonolite or porphyry. The quantity and character of the added salts vary. In the case of large vessels we aim to obtain a mass with a low coefficient of contraction; in the preparation of small vessels the material must be fairly plastic and the mixture made to obtain such a result.

The composition of the glazes varies greatly. Sometimes the feldspar is absolutely replaced by lime, when we obtain a clear glaze; when the lime is replaced by feldspar the glaze may be milky.

The latest products of the chemical-supply manufacturers include the acidproof corundum articles made from ground and cleaned corundum and clay. One recipe* calls for 84 parts ground corundum, 37 parts of clay and 9 parts of corundum dust. The resulting product shows almost no shrinkage on burning and is most refractory to change of temperature and the tax of acid.

Acidproof Brick. — By acidproof or acid-resisting bricks we mean those which are used in the chemical industry under such conditions that they must resist attacks of acids, such as hot sulphuric acid in Glover and Gay-Lussac towers. The selection of the material for such bricks and tile is limited. It must burn dense and contain little of such chemical constituents as the oxides of iron and lime. In order to obtain these requirements it is usual to add from 5 to 10 per cent of feldspar to the clay selected, producing a mixture similar to that used in making hard porcelain which contains from 40 to 50 per cent of clay, 25 to 30 per cent of quartz and 25 to 30 per cent of feldspar. This mixture burns dense at a temperature considerably below its melting point. It is seldom that we find clays of the required composition. Since the color of the resulting brick is of little consequence we may add to the original clay such additions of feldspathic minerals as porphyry or phonolite in order to produce the sintering and dense burning at a low temperature. A brick of the following composition gave good results: silica 72.11, alumina 20.58, ferric oxide 5.48, lime 0.92, magnesia 0.54. It is advisable for certain purposes to glaze the brick with one of the readily-fusible lead-free glazes; such a glaze, invented by Seger, is of the following composition: feldspar 42.1 per cent, marble 17.7 per cent, kaolin 13.0 per cent, sand 27.2 per cent and corresponds to the formula

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* Kerl, *Handbuch der gesammten Thonwaarenindustrie*, p. 1320.

$$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}\ 0.5\ Al_2O_3 4\ SiO_2,$$

the constituents of Seger cone 4 which melts at 1210° C.

Messrs. Seger and Cramer, in examining bricks and tile which are determined for acid-resisting purposes, pursue the following method:

The sample of brick or tile is crushed, in order to have as large a surface as possible, and exposed to the action of acid. Grain which passes a 20-mesh, but not a 25-mesh, sieve is selected for the test. The grain is washed and dried. Then 100 grains are placed in a platinum dish and covered with an acid mixture consisting of 10 per cent nitric acid (specific gravity 1.4), 25 per cent concentrated sulphuric acid and 65 per cent water. The mass is heated to boiling and kept at that temperature until the water and nitric acid are volatilized and the sulphuric acid fumes. The whole is now cooled and then reheated to boiling point with water and nitric acid. The supernatant liquor is now decanted, and the mass washed with water until no traces of acid remain. It is then dried and weighed and the loss calculated. Good material loses only 1 to 3 per cent.

The figures from such determinations are to be regarded as relatively correct only, since almost all clays and glasses are slightly soluble in acids.

Mortars for Acidproof Bricks. — Should the bricks not be laid loose on one another, as in the Glover tower, but require mortar, a mixture made by melting asphalt or infusorial earth with paraffin is satisfactory.

Muller * recommends a cement consisting of carborundum, sand and magnesium oxychloride. The H. W. Johns-Manville Company makes an asbestos mortar and cement especially for pointing acidproof bricks and jointing acidproof ware. The composition is not published, but it is probably a mixture of magnesia and asbestos, with possibly some such bonding agent as sodium silicate.

Quartz and Silica.—The silicious refractories used in the chemical industries do not strictly include silica brick which consists of ground sandstone or quartzite bonded with 2 per cent of lime, and contain about 2 per cent of other bases and is, accordingly, vulnerable to the attack of acid. As far as resistance to high temperature only is concerned these bricks are satisfactory. They are desirable in furnace operations on account of their even modulus of expansion and their ability to withstand changes of temperature as well as the attack of acid gases and slags. The chief silicious refractory of importance to the chemist is quartz in the form of fused silica ware, and of cut and worked rock crystal. Mr. A. E. Marshall, in a paper read before the New York section of the American Chemical Society, has described the properties of electrically-fused silica. This material, made by the Thermal Syndicate, is replacing the ground-quartz or rock-crystal articles, which, while transparent and attractive to the eye, are much too expensive to be used on a large scale. Furthermore, it is almost impossible to manufacture articles of such large dimensions from rock crystal as are now produced from fused silica.

Fused Silica Ware.† — The production of fused silica apparatus in sizes suitable for manufacturing operations was made possible by the Thermal Syndicate's electric-furnace process, which was patented in 1904. Prior to that date small transparent articles had been made by various experimental workers from rock crystal.

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* *Thonindustrie Zeitung*, 1905, p. 69.

† A paper read before the New York Section of the American Chemical Society on March 8, 1912, and published in *Metallurgical and Chemical Engineering*, April, 1912.

The method generally adopted was to build up the article from small pieces of crystal in an oxyhydrogen blowpipe flame. The size of these vessels was, of course, limited, but despite this and their necessarily high cost they were used where the peculiar properties of the ware rendered it more serviceable than other materials.

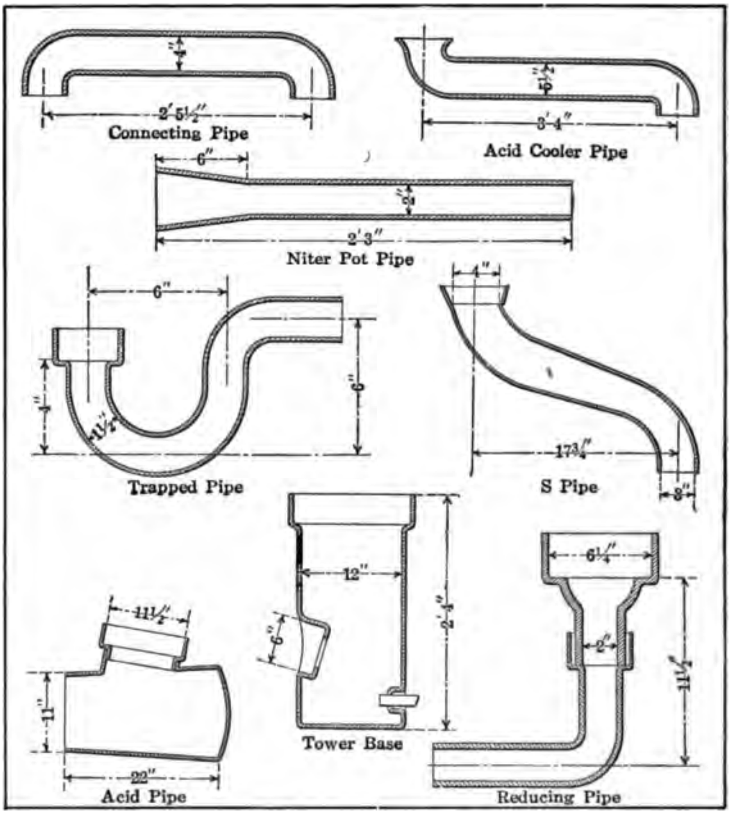

FIG. 73. — Fused Silica Ware. (Made by the Thermal Syndicate Ltd.)

The electric-furnace process of fusing pure silica is applicable to the manufacture of large and small apparatus, the maximum sizes being pipes of 12-inch diameter and 30 inches long, basins 20 inches in diameter and retorts of 75 litres' capacity. The articles made by this process are not transparent like the rock-crystal product, as the mass does not becom during fusion, but only attains a plastic consistency, with the result that the small air bubbles disseminated through it are unable to rise to the surface.

The small ware intended for laboratory purposes is subjected to a special process which increases the transparency and gives the material a highly glazed surface. The glaze is of the same composition as the ware; that is to say, it is pure silica and is not added alkaline glaze. The application of the glazing process is at present limited to ware not exceeding 6 inches in diameter.

Fused silica possesses qualities which render it of great value in the allied chemical industries, such as its property of resistance to heat and to acids. It is highly refractory, the melting point (which is not well defined) being between 1700° C. and 1800° C. The material softens appreciably at lower temperatures (about 1500° C.), but does not readily lose its shape.

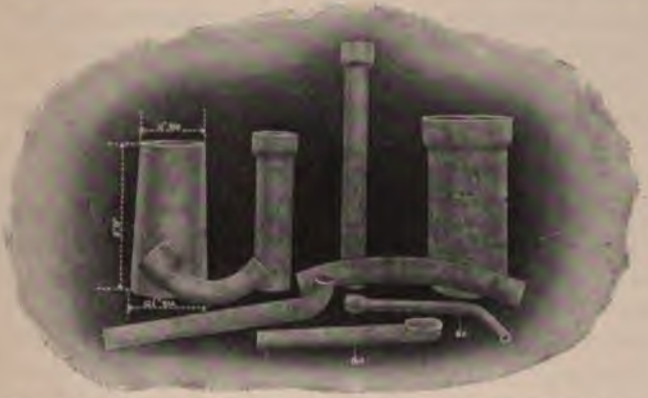

FIG. 74. — Tubes of Electrically Fused Silica produced by the Thermal Syndicate.

A characteristic of fused silica which is sometimes overlooked is its tendency to devitrify or to pass from the vitreous to the crystalline state, if it be continuously heated above 1200° C. This, of course, does not prevent the use of the material for intermittent work at temperatures considerably greater than 1200° C.

The ware is unaffected by acids, with the exception of hydrofluoric and phosphoric acids. In the latter case the action becomes pronounced at 400° C. Most alkalies attack it very slowly.

The electrical insulating value of fused silica is high, and the resistivity decreases very slowly with a rise in temperature.

There are also various types of electrical heaters or radiators in use in England and in Continental Europe, consisting of a heating element of nonoxidizable wire enclosed in thin walled tubes of fused silica.

In the chemical industry, fused silica has found application, in the construction of sulphuric, nitric and hydrochloric acid plants. Certain operations, such as the concentration or distillation of sulphuric acid, have always presented difficulties to the manufacturer by reason of the failure of the material from which the plant has been built. In some cases costly vessels of platinum or platinum-iridium have been used to overcome the difficulties.

Fused silica has been adopted for these two operations, some forty basin-type concentrators being in daily use in England. The silica basins are invariably exposed directly to the fire gases.

In the case of nitric and hydrochloric acids fused silica pipes have been extensively applied in place of earthenware. The pipes are made in the usual shapes with either socket or tapered joints. Considerable care is necessary in making the joints, owing to ordinary jointing materials and cements having coefficients of expansion considerably greater than silica. The best form of joint is one relying on asbestos for the main portion of the joint, the outside only being finished with cement.

Italian asbestos must always be used, as the Canadian variety swells considerably when brought in contact with strong acids.

A large variety of special shapes of apparatus, such as coils, tanks, retorts, crucibles, etc., are made for various branches of the chemical industry where either resistance to acids or heat or a combination of these properties is desired.

It is interesting to note that ware of an ornamental character, such as finger bowls, fruit plates, etc., having a highly lustrous surface, can be made by the same process as the chemical ware. The luster is due to the reflection of light from the surfaces of highly distended air bubbles, and it is, therefore, untarnishable.

Glass. — Ordinary glass is in no sense refractory to heat, but it is resistant to acid attacks. In the transition from glass to porcelain, we obtain products which are somewhat less fusible, such as cryolite glass, consisting of silica, cryolite and zinc oxide; this is known as hot-cast porcelain. One cryolite glass was made from the following charge: 67.19 per cent silica, 23.84 per cent cryolite and 8.97 per cent zinc oxide.

The chemical glassware, which is made to withstand medium temperatures, and which is subjected to frequent and somewhat sudden changes of temperature, consists of charges of two or three kinds of glass of known coefficients of expansion, which are melted together with the object of obtaining a glass product which is resistant on the exterior to the influences of changes in temperature. This is done by cooling the glass rapidly in the air, when the outside of the glass body is in compression, and the much more slowly cooling interior is in tension, or a melt of glass mixture of low expansion coefficient may be poured about the original glass.

The Alumina-Silica Refractories. — These are differentiated from the fire-clay and clay refractories in that they contain a surplus rather of alumina than of silica. Among these are: (1) alundum, (2) bauxite, (3) alusil, of which the first is of importance to the electro-metallurgist.

Alundum is made by fusing the mineral bauxite in the electric furnace, when it becomes practically pure alumina, crushing the furnace ingots (each of which weighs 3 tons) to grain of various sizes, bonding with small quantities of suitable materials, such as bauxite or fire clay, which will not lower the resistivity of the alundum to the influences under which each different kind of vessel is used, shaping the vessel and burning at a high temperature.

The alundum articles of special interest to the industry include electric-furnace cores, tubes for high-temperature electric-furnace work, muffles, crucibles, combustion boats and alundum filters. The ware is porous and vessels may be used for rapid and thorough filtration of liquids, both basic and acid, from precipitates. In addition to the solid ware, alundum is used in the form of a dry powder, which, when mixed with water and made into a thick paste, may be used as a cement. On burning this cement a body results which is as refractory as the alundum ware. The Norton Company advertise the physical properties of alundum in the following description of its qualities.

"The melting point of alundum is approximately 2100° C. (3800° F.) and that of the bonded refractory articles slightly below this, depending on the kind of bonding materials used to obtain the properties desired

"Alundum crucibles have been used over and over without injury for melting pure platinum.

"The thermal conductivity of the bonded pieces is very high compared with other refractory materials ordinarily employed, being 2.1 times that of ordinary fire brick and 1.6 times that of chemical porcelain. This material, therefore, is highly efficient for furnaces, muffles, etc., where the heat is applied from the outside.

"The electrical conductivity of alundum is low up to temperatures near its melting point, and it can be used for electrical insulation for low-tension work.

"Alundum is resistant to the action of most chemicals.

"Having a comparatively low thermal coefficient (7.1×10^{-7}) it is not affected greatly by changes in temperature.

"The mechanical strength of alundum refractories can be varied to meet conditions, the maximum being a crushing strength of 15,410 pounds, or 7½ tons per square inch, and a tensile strength of 1700 pounds per square inch. The mechanical strength is dependent on the thermal conductivity, coefficient of expansion and other properties desired.

"The porosity of alundum refractories can be varied, but it is not possible to make absolutely non-porous bodies of this material without sacrificing its refractory qualities.

"The specific gravity of alundum is 3.91."

Besides the white and pure material, a brown alundum is also marketed; this melts at a temperature 50° C. below the melting point of purer materials, viz., at about 2000° C. The linear coefficient of expansion of a white variety is 78×10^{-7} as compared with 85×10^{-7} of the brown product. The Norton Company has developed preparation of crucibles, muffles, tubes, etc., and now manufactures such apparatus as thermocouple tubes. These have a higher modulus of heat conductivity and are more refractory than any of the porcelain or fire-clay tubes. They have also, accordingly, the property of eliminating to a great extent the lag in the temperature indications which results sometimes in pyrometric work, in which the changes of temperature are such that the conductivity of the pyrometer tube becomes a factor to be considered. Mr. L. E. Saunders had discussed the properties of alundum in a paper read before the American Electrochemical Society.* Alundum bricks have also been tested by Messrs. FitzGerald and Bennie † from whose paper the following description of the properties of this material is taken.

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* Transactions of the American Electrochemical Society, Vol. 19 (1911), p. 333.

† *Metallurgical and Chemical Engineering*, March, 1912.

"In the Norton Company's experimental department a furnace roof was made of alundum bricks and the remarkably high temperature these would stand, without giving way, demonstrated their usefulness beyond doubt. The temperatures used in the experiments were so high that a roof built of silica bricks was destroyed in 5 or 6 hours, while 40 or 50 heats at similar temperatures with the alundum roof failed to make it useless. On the other hand, experiments with roofs built of alundum bricks in a steel furnace did not give results which came up to expectations, although the temperatures were by no means so high as in the furnace referred to above.

"The problem of constructing a good roof for a steel furnace of the surface arc type has been the subject of careful study of the FitzGerald and Bennie laboratories in conjunction with the research department of the Norton Company. Alundum bricks made up in various ways have been tested in a small single-phase, two-arc steel furnace. These experiments have clearly shown that while alundum bricks will successfully resist the temperature of the electric steel-furnace roof there are difficulties in the way of using them for that specific purpose. The bricks when used in the steel-furnace roof showed a tendency to break off in layers and careful analyses soon showed that this was due to the action of the lime vapors rising from the intensely heated basic slag used in the furnace. The action in fact was altogether analogous to that pointed out by Hansen in his discussion of Saunder's paper, showing that in the steel furnace the stalactites which formed on the roof contained a relatively large percentage of lime and magnesia. The lime and magnesia vapors at high temperatures react with the alundum brick and thus shorten the life of the roof. The final conclusion reached, as a result of the study, was that while alundum bricks could be made which would certainly outlast silica bricks when used as a furnace roof, the increased life was not sufficiently great to warrant the extra cost of the special refractory in this particular case."

The Carbon-Silicon Refractories. — These include carborundum, the name given to the pure crystalline carbide of silicon, and siloxicon, or the more or less oxidized amorphous carborundum to which the formula $C_xS_zO_y$, has been given. These two terms of the carborundum company represent respectively the crystalline and amorphous crystolon of the Norton Company. The amorphous crystolon is sometimes known as carborundum fire sand.

Messrs. FitzGerald and Bennie have published the results of some of their experiments with these refractories.*

Carborundum. "Carborundum fire sand," as a lining in various forms of resistance furnaces, gives good results. For example, when it is desired to heat crucibles by embedding them in a resistor composed of granular carbon, trouble is often experienced at high temperatures by the melting of the fire brick forming the sides of the trough containing the resistor. If now the brick trough is made a little wider and then lined with amorphous silicon carbide to a thickness of 1 inch no trouble at all is experienced.

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* *Metallurgical and Chemical Engineering*, Vol. X, No. 3.

In many fuel-fired furnaces this refractory also gives excellent service in the form of bricks or linings, or even as a wash applied to the fire-brick walls. It can be usefully applied in making repairs to furnaces and as a cement for setting up fire brick.

When the amorphous substance is heated to excessively high temperatures it becomes somewhat plastic and eventually in a reducing atmosphere is converted into the crystalline variety of silicon carbide. The fact that it becomes somewhat plastic at very high temperatures makes it possible, in special cases, to use it as a lining, etc., without any binding agent whatsoever.

Amorphous silicon carbide is not a good heat insulator. Its heat conductivity while not very high is, nevertheless, distinctly greater than that of ordinary fire-brick structures.

Crystolon. Formed at a higher temperature than the amorphous form, crystalline silicon carbide, or "crystolon," is a still better refractory material for many purposes. Under ordinary conditions it is infusible, but when heated to a high temperature in a reducing or neutral atmosphere it is decomposed, the silicon vaporizing and the carbon remaining behind as graphite. If heated to a sufficiently high temperature in a strongly oxidizing atmosphere, slow oxidation occurs, the carbon burning to carbon monoxide and the silicon forming silica. The latter appears to form a protective coating which prevents further oxidation, or at least prevents it from proceeding rapidly.

Experiments have been carried out in the Norton Company's Research Department on various articles made of crystolon grains or powders mixed with suitable binding agents, and so far the results obtained are found to be highly satisfactory; but more time and work have been expended on the study of crystolon made into various forms without the use of any binding agent. These articles are made according to a method patented by FitzGerald. Silicon carbide in the form of grains or powder is mixed with some temporary binder, such as a solution of glue or dextrine, the mixture moulded in the desired form and then heated in an electric furnace to the temperature at which silicon carbide is formed. This causes a crystallization or recrystallization of the silicon carbide and a strong, very refractory article is obtained. These are known as "pure crystolon" bricks or tubes, in order to distinguish them from bonded crystolon articles.

Most of the experiments which have been made with pure crystolon have been with bricks made of that material. As was already pointed out the bricks are infusible under ordinary conditions. The coefficient of expansion by heat is small, much less than that of silica for example. The heat conductivity is higher than that of alundum. This is well shown in Fig. 75, where curves are given which illustrate the relative capacity for transmitting heat of silica, alundum and pure crystolon bricks.

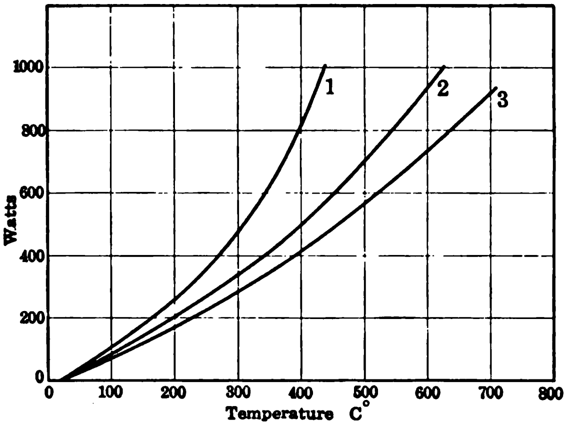

FIG. 75. — Comparative Heat Conductivities of (1) Crystolon, (2) Alundum, (3) Silica.

The method of obtaining the data from which the curves were plotted was to build a small furnace of the bricks under test and to place therein a resistor through which a measured current could be passed. Through a small hole in the wall of the furnace a thermocouple was passed so that the temperature of the interior could be measured. The furnace was then heated with a definite current and when the temperature was constant both it and the watts were noted. This gave the amount of energy passing through the walls of the furnace for the particular internal temperature. In the curves the abscissæ are temperatures in the furnace and the ordinates are watts, giving in that unit the rate at which heat is flowing through the walls. Curve 1 is for the pure crystolon brick, curve 2 the alundum bricks and curve 3 a silica brick. It is very clear that the capacity of the crystolon brick for transmitting heat is very great compared to other refractories. Thus when the temperature in the furnace is 435° C. the crystolon brick transmits 79 per cent more heat than the alundum brick and 117 per cent more than the quartz. The crystolon brick is, therefore, a very efficient refractory where it is desired to transmit heat, but, on the other hand, where good heat insulation is necessary it is important to back up the crystolon with a suitable heat insulator.

There have not been any thoroughly satisfactory quantitative experiments made on a large scale to study the efficiency of crystolon as a transmitter of heat, but two tests may be mentioned which give some indications on this point. A furnace having a capacity of 75 to 100 kw. was constructed, in which the resistor heated the reaction chamber by radiation. Between the resistor and the reaction chamber was a septum built of crystolon tile 1 inch thick. Temperature determinations made with a thermocouple on both sides of the septum showed a very small difference in temperature when the furnace was at high temperatures. In this relation the form of curve 1 in the figure should be noted, as this indicates that the heat conductivity increases in marked degree with increased temperature.

The other experiment was a comparative one made with two pyrometer tubes, one made of a refractory clay and the other of graphite and crystolon. The dimensions of the tubes were identical, but the special tube was built up of two tubes, the inner one being of graphite and the outer one of crystolon. The experiment was made by introducing the cold tubes into the furnace, the temperature of which was kept constant, and then noting the time taken for the pyrometer to come to a constant reading. In the case of the clay tube the time was 38 minutes, while the graphite-crystolon tube reached a constant temperature in 15 minutes. It was, moreover, observed that the clay tube gave a pyrometer reading 10° C. lower than the other.

The most important study that has been made of the use of pure crystolon is in the building of the roofs of electric furnaces. The experiments have been made both in the FitzGerald and

Bennie laboratories, where the crystolon bricks were manufactured, and also in other works. The laboratory furnace was a small one having a capacity for about 500 to 600 pounds of steel, but it was possible to use a current of 150 kw. Moreover, in constructing the furnace the hearth was built very high so that in some cases the surface of the bath was only 8 inches from the roof of the furnace. This, of course, made the test a very severe one.

Certain characteristics of pure crystolon make it necessary to construct the roof of the furnace in a special way. In the first place the high heat-conductivity of pure crystolon would cause serious losses from a roof built in the ordinary way. This was clearly demonstrated by building a roof of pure crystolon brick, 9 by 4½ by 2½ inches, with the bricks placed so that their longest dimensions were vertical. When the furnace was worked on steel in this way it was impossible to heat it properly on account of the rapid flow of heat through the roof. After that the roof was built in two courses, the lower one consisting of crystolon bricks laid so as to form a roof 4½ inches thick, and the second course consisting of fire brick also 4½ inches thick. This was found to be a perfectly satisfactory arrangement. It has also the advantage that the number of crystolon bricks required to form a roof is reduced one-half in this manner.

The other characteristic of crystolon which makes a special construction necessary is its electrical conductivity at high temperature. This phenomenon can be well illustrated by a simple experiment. If a rod of pure crystolon is wound with copper wire at both ends so as to make a good contact and connected to a source of electrical current, very little will pass, but if the rod is heated with a blast lamp to a high temperature the current will pass freely. Crystolon refractory articles made up with a small amount of a clay bond do not become conductors even at high temperatures, although the resistivity is considerably diminished. The following determinations of the resistivity of bonded crystolon have been made:

Temperature. °C.	Resistivity. (Cm. cube.)
20	318 × 105
656	63 × 105
809	32 × 105
940	16 × 105
1040	4 × 105

It will be observed that although there is a considerable decrease in resistivity with rise in temperature, yet for most practical purposes the crystolon remains an insulator.

If now the pure crystolon brick were used to build an electric-furnace roof through which two electrodes at different potentials passed there would be serious current leakage when the roof becomes hot if the electrodes touched it. It is, therefore, necessary to have a clearance between the electrodes and the brick by making the openings in the crystolon roof somewhat larger than is customary with the ordinary roof. On the other hand, the heat-insulating bricks used on top of the crystolon roof form openings that are of the normal size. This method of constructing the roof is found to be perfectly satisfactory.

In the tests made at the FitzGerald and Bennie laboratories it was found that when using ordinary brick and overloading the furnace there was no difficulty in completely destroying the roof in a single heat, but this was impossible in the case of the crystolon roof. When the crystolon roof is used it is possible so to overload the furnace that the magnesia lining is destroyed and yet the roof remains intact.

Experiments have also been made on 2-electrode steel furnace in which the capacity was 2.5 tons of steel, and these in every respect confirm the results already mentioned.

It is certain that, provided a sufficiently high temperature is reached, there is a reaction between lime and silicon carbide, but so far as the tests made with the crystolon roofs go there is no appreciable reaction between the lime vapors from the slag and the brick.

The pure crystolon brick has been tested also in other ways. Thus, in one furnace in which a certain material was heated to excessively high temperature, it was found that a good grade of fire brick used outside the crystolon brick for heat insulating purposes could be melted down completely by the heat transmitted by the crystolon brick without in any way damaging the latter.

Other examples could be given, but enough has been said to show that this refractory material promises to have important uses, making it possible to do things which were impossible hitherto. For example, in the electric steel furnace not only may the space between the roof and the bath be made much smaller but the temperature may be forced to a higher degree without any risk of damage.

The crystolon brick is, of course, a somewhat expensive refractory and consequently much of the investigating work done on it has been in the direction of improving methods of manufacture so as to reduce the cost. So far as moulding goes the problem is comparatively simple, but the development of a satisfactory furnace for "baking" the brick proved more difficult. However, a satisfactory furnace has been designed and worked until it appears to give excellent results.

The Basic Refractories Used in the Electro-metallurgical Industry. — The chief of these is magnesia which has a wide use as a refractory in spite of its serious faults. The most serious of these is an objectionable way of cracking when heated to a high temperature. This is, no doubt, in large part due to the remarkable way in which magnesia articles shrink when heated to high temperatures, corresponding to the increase in the absolute density.* An experiment of Moissan is thus epitomised:

"The first specimen (of magnesia) had been heated for 6 hours in a furnace heated with an air blast and retort carbon as fuel. The second specimen consisted of magnesia plates, partly crystalline, which had been submitted for 2 hours to the action of the electric arc. The third consisted of a mass of magnesia weighing 50 grams and fused into a single piece in the electric crucible furnace. We obtained the following:

	Density at 20°.
1. MgO (furnace with blower)	3.577
2. MgO (furnace with plates)	3.587
3. MgO (fused mass)	3.654

Moreover, Ditte has shown that magnesia gives the following densities:

	Density at 0°.
At 350	3.1932
Dull red	3.2482
White heat	3.5699

Under the circumstances it is not surprising that articles such as brick and crucibles are apt to crack when heated to high temperature.

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* *Metallurgical and Chemical Engineering*, March, 1912, p. 130.

It is obvious that the tendency to cracking exhibited by the ordinary calcined magnesite is less likely to be found in a material which has been calcined at the very much higher temperatures attainable by electric means. An experiment which brought this out very clearly was as follows: A crucible was made of highly calcined magnesia prepared from Grecian magnesite. The crucible was embedded in a granular carbon resistor and the current regulated so as to heat the crucible very gradually. The crucible was finally raised to an intense white heat, probably about 1500° C., and was then allowed to cool gradually in the furnace. It was so badly cracked that it was absolutely useless. Another crucible was made in exactly the same way except that electrically calcined magnesia was used. This crucible was heated fairly rapidly to a temperature at which Seger cone 35 (supposed to bend at 1830° C.) was completely fused. The crucible was then allowed to cool and was examined. A few very small cracks had occurred where a hot spot unfortunately developed during the process of heating, but otherwise the crucible was in perfect condition. The heat had been so intense that the outside of the crucible was slightly fused.

Several tons of magnesia have been electrically calcined and tested in a great variety of furnaces, and in every case excellent results have been obtained.

There is one other important point to note in regard to this highly calcined material. The ordinary calcined magnesia absorbs carbon-dioxide gas, forming magnesium carbonate more or less rapidly, but this does not occur at all, or with extraordinary slowness, in the case of the electrically calcined product. An experiment demonstrated this very clearly. Two porcelain boats were filled with electrically calcined magnesia and a highly calcined magnesia of the ordinary kind, respectively. In both cases the samples were finely ground so that the particles were of approximately the same size. The boats were placed in a tube through which a rapid stream of moist carbon-dioxide gas was passed for 44 hours. At the end of that time the samples were weighed with the following results:

Sample.	Per cent increase in weight.
Ordinary calcined	31.30
Electrically calcined	0.00

In the preparation of this magnesia it is possible to use an arc furnace, but the method is not altogether satisfactory on account of its cost. It is unnecessary, and in fact disadvantageous in many ways, to fuse the magnesia. Accordingly a resistance furnace has been worked out which will calcine the magnesia satisfactorily.

Electrically Fused Lime. — This product may be found very useful in the electric-furnace industry. FitzGerald reports that lime fused in the electric furnace is a much better conductor of heat than ordinary quicklime. Blocks cut from the fused product stand heating followed by sudden cooling very well. One such block was heated to redness with a blast lamp and while still under heat cold water was poured on the block without producing any change. Fused lime resists exposure to moist air remarkably well, for while it will eventually slack, this is a process of days instead of hours. Even when boiled with water, hydration proceeds very slowly.

Electric-furnace Linings. — These may be classified according to use: (1) in reduction smelting furnaces, and (2) in steel and refining furnaces.

In the first class the experience of the Trolhätten smelters has taught us that linings of ordinary fire clay and magnesia will easily withstand the heat and chemical effects produced in electric smelting of ores. The Trolhätten furnace reduces about 23 tons of pig iron per day. During an operating period of 5 months only 18 hours have been required for keeping the crucible in good repair; apparently the lining of the furnace was not severely damaged in the same time.

The operation consists in smelting iron ore, by means of arcs produced by 4 to 6 electrodes from three-phase alternating current, in a circular shaft furnace which bellies into a crucible of larger diameter. Carbon, in the form of charcoal, does the reducing while the heat of the arc attends to the fusion and slag formation in the crucible; the ore is heated and partially reduced in the shaft by the ascending gases. The waste furnace gases are recirculated in order to realize the reducing power of their carbon monoxide. They serve also to cool the crucible lining both by absorbing some of the excessive heat which it contains, and by demanding heat to effect the dissociation of carbon dioxide and aqueous vapor in contact with the incandescent carbon which descends to the crucible. The furnace consists of the three parts, shaft, bosh and crucible. Each of these is confined by a shell of steel plate, respectively 0.4, 0.5 and 0.5 inch thick. The thickness of the lining is respectively 1 foot 6 inches, 1 foot 2 inches and 1 foot 6 inches. In the shaft and bosh it is of fire-clay brick. In the crucible the outside brick next to the shell is of fire clay; inside this is a lining of magnesia. The crucible is roofed with fire-clay brick and

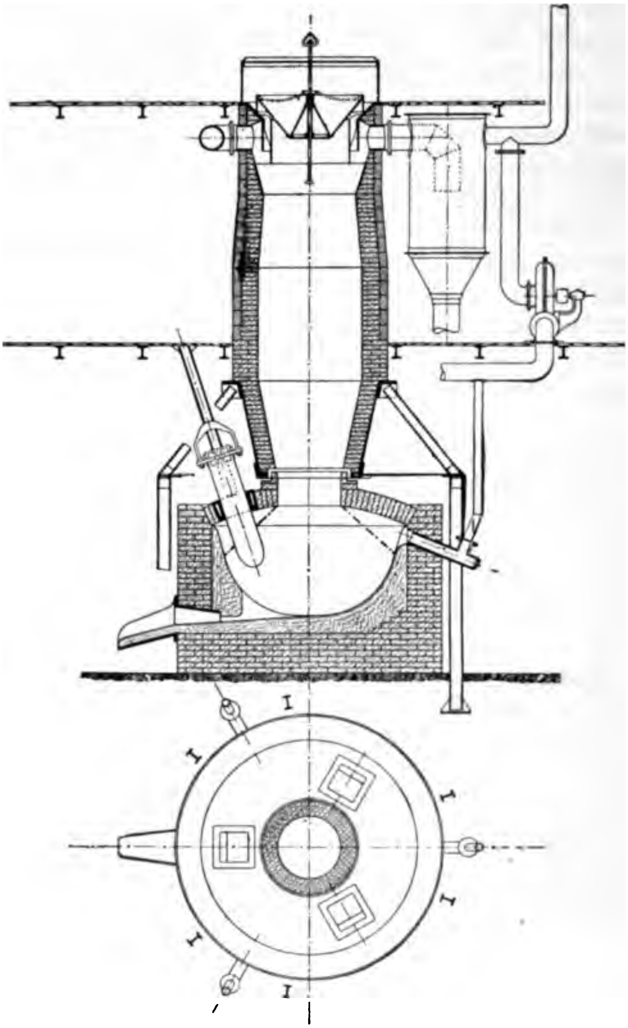

Fig. 76. — Electric Arc Furnace for Smelting Iron Ore.

the opening to the bosh of the shaft is sealed with sand. The roof is also broken to permit the entrance of the 4 electrodes, each of which is composed of 4 carbons of square section. The bottom of the crucible is dish-shaped and is formed of a mixture of magnesia and pitch rammed in so as to extend for some distance along the walls. That part of the waste gases which is blown back through the furnace enters by 4 tuyeres attached to the bustle pipe encircling the crucible. An effort was made to cool the electrodes by blowing the gas through them, but the carbon dioxide attached and destroyed the carbon. The slag and iron are often tapped from the pig tap and the slag has been skimmed from the molten pig.

Mr. Van Brussel * enunciates the following principles of construction:

(1) As all known materials become good conductors at a high temperature, the construction must be such that the current does not pass through the lining during the working. (2) The construction must be such that the charge itself protects the lining from destruction through radiation from the electric arc or through conduction; otherwise it would be necessary to employ water cooling with consequent waste of energy. (3) The charge must not press harder against the electrodes than is necessary for the formation of an arc. If this condition is not fulfilled the tension becomes unduly low, the electrodes and conductors assume inordinately large dimensions and the working becomes irregular. In the electric smelting the carbon charged with the ore cannot burn, and for obtaining a product of uniform quality it is necessary to have a hearth of sufficiently large dimensions to serve as a mixer. Otherwise the irregularities which inevitably occur in charging will influence the carbon contents, etc., of the product. In order to fulfil these conditions the hearth is constructed in the shape of a comparatively large crucible covered by an arched roof.

Another important feature in a furnace of this kind is the regulating of the energy supply. As a reduction furnace must necessarily work with a considerable gas pressure, the usual method, consisting of raising or lowering the electrodes, cannot be conveniently employed, as it would be too difficult to keep the packings tight around the electrodes. A system has been elaborated by which the electrodes are generally adjusted in accordance with their wear, but all other regulating is accomplished by varying the

* *Engineering and Mining Journal*, Sept. 30, 1911, p. 651.

tension of the current supply. This is done by cutting out windings on the high-tension side of the transformers, and the arrangements are such that the different phases can work simultaneously with different tensions; for instance, 80 volts on one phase and 70 volts on the other, etc. This method of regulating the current has greatly facilitated the working.

The linings of resistance furnaces and arc furnaces used for smelting, refining and calcining are made of magnesia or crystolon. Silica and, less often, fire clay and alundum are also used in these furnaces, especially in the roofs. The uses of these materials in this way has been discussed in previous chapters and on pp. 191–193.

In some electric furnaces a refractory lining is not needed since the heat is developed in the midst of a large mass of material. An example of this construction is the Acheson carborundum furnace and the Wilson carbide furnace. In the case of the continuous electric smelting furnace of shaft and crucible type, the current may be regulated so that a portion of the ore, which otherwise would descend through the shaft, remains unfused around the sides. In processes, however, in which the charge is heated considerably above its melting point, the hot liquid central part will gradually eat its way through the unfused ore to the walls. The sides may be cooled by a continuous passage of cold air or water on the outside, or of fresh ore on the inside. A satisfactory method of water-cooling electrolytic furnaces is described by Stansfield.* The molten electrolyte is contained in an iron vessel which is required to be gas-tight. Since both the electrodes pass through the walls of the vessel, or the vessel itself may be one electrode, it is necessary to introduce an insulating joint at some point and the joint must be unaffected by heat, by the electrolyte or by the gases given off in the operation. A satisfactory method of effecting this is to make the vessel in two parts, one of which may be the lid, and to maintain, by water cooling, a layer of solidified electrolyte between the two parts, which are slightly separated. This method is employed in Borchers' appliances for the electrolysis of fused zinc chloride and for the electrolysis of fused salts of lead.

Electrode holders are sometimes water cooled, to prevent them from becoming unduly heated, and occasionally even the electrodes themselves are water cooled as, for instance, the water-cooled iron electrode in Borchers' aluminum furnace.

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* "The Electric Furnace," p. 60.

CHAPTER X

SOME INSTANCES OF APPLICATION OF COMMON AND REFRACTORY BRICKS IN INDUSTRIAL FURNACES

Cement Kilns. — Fig. 77 shows clearly the method of lining a rotary cement kiln. The shell of strong steel plate is lined with 6-inch rotary kiln blocks for somewhat more than half its length where the temperature is not relatively high; the remainder of the shell, towards the discharge, is covered with 9-inch blocks. These are all specially made for standard diameters and with the exception of the blocks at the top of the arch are easily laid in position. Fire clay is still the most generally used refractory material; the highly aluminous brick known as "alusil" is probably used as much in this work as in any. Magnesia, chrome and bauxite bricks have been used. Claims

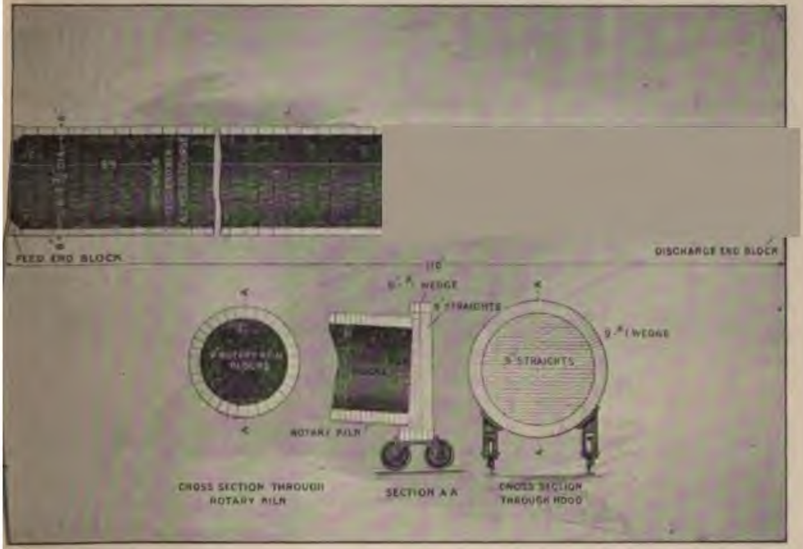

Fig. 77. — Standard Rotary Cement Kiln.

are made that the bauxite of the present day is so superior that it outlasts any other bricks in the cement kiln. The action of the high temperature employed (up to 1500° C.) and of the cement in scouring and attempting to form lime silicate salts with the lining make imperative the use of a refractory of good physical and quite neutral or basic chemical qualities.

Glass Furnaces. — Fig. 78 shows a cross section of a glass tank furnace heated by producer gas and provided with checker work. The latter system of realizing energy in waste gases was first used in the glass furnaces developed by Frederick Siemens in Dresden. The floor, side lining and roof are sometimes all made of silica blocks and bricks, but as a rule the bottom blocks and sides beneath the surface of both are of refractory fire clay.

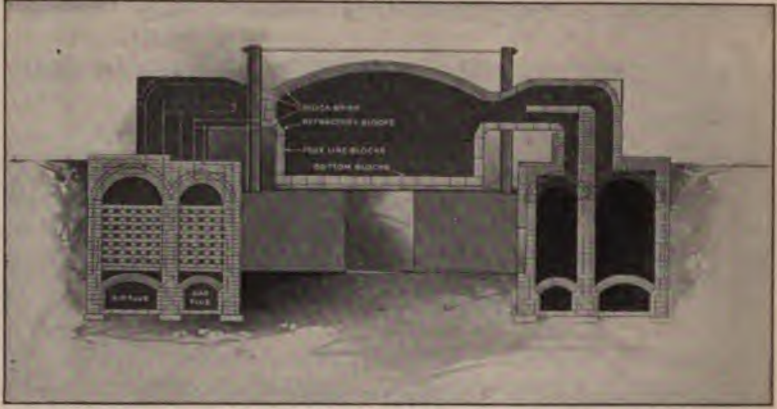

FIG. 78. — Section through a Glass Furnace.

Lime Kilns.*—These are now built with a clear width of 9 feet 6 inches, 30 feet in height from the bottom of the fire box to the top of the lining, and 48 feet in total height. The shell of boiler plate carries 25 inches of lining. In the top half of the shaft, the inside 9-inch course of first quality fire brick butts against 16 inches of second quality fire brick; in the lower half there are two 12-inch thicknesses of both first and second quality fire-clay brick. The arches and bridge walls of the five or six fire boxes at the bottom are of first quality fire-clay brick.

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* See illustration on page 41.

Cupolas. — Cupolas for melting iron and alloys carry a lining of fire-clay brick, 10½ to 12 inches thick, from the tapping hole to the feed door. The shaft above the feed door is lined with 4½ inches of fire-clay brick. These shapes are specially prepared to fit the circumferences of standard-sized cupolas. Gas-producer shaft linings resemble the linings of cupolas. Their boshes are generally made of cast-iron plates; the lining of the shaft inside the shell is of good quality fire-clay brick.

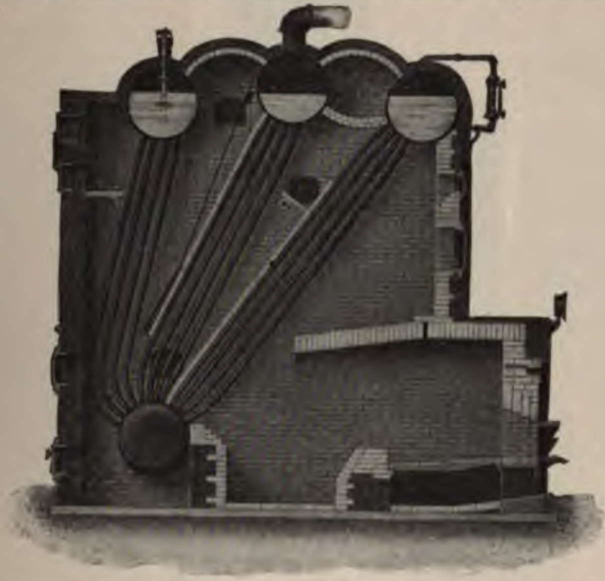

FIG. 79. — Sterling Water-tube Boiler.

Incinerating Furnaces. — All of these furnaces are lined with 4½ or 9 inches of first quality fire-clay brick, butting against 9 or 13½ inches of second quality fire brick.

Tile. — Tile for flues, furnace doors and roofs are made of fire clay and measure generally up to 30 by 12 by 2 inches. When made larger than this, and most refractories manufacturers make them up to 3 feet in length, they must be made at least 3 inches thick to carry their own weight.

Boilers. — In no field has there been so much waste of bricks and refractory materials as in the settings of boilers. Third quality and common brick break up when exposed to the heat and strains usual in these settings. Concrete should be used sparingly near the ash pit and fire box. Lime mortar should not be used except in parts which are permanently cool. Figs. 79 and 80 illustrate the methods of laying bricks in the settings of such as the Sterling and the return tubular boilers. A detailed description of the manner of setting is presented in the following specification for the erection of two 350-h.p. Babcock and Wilcox boilers.

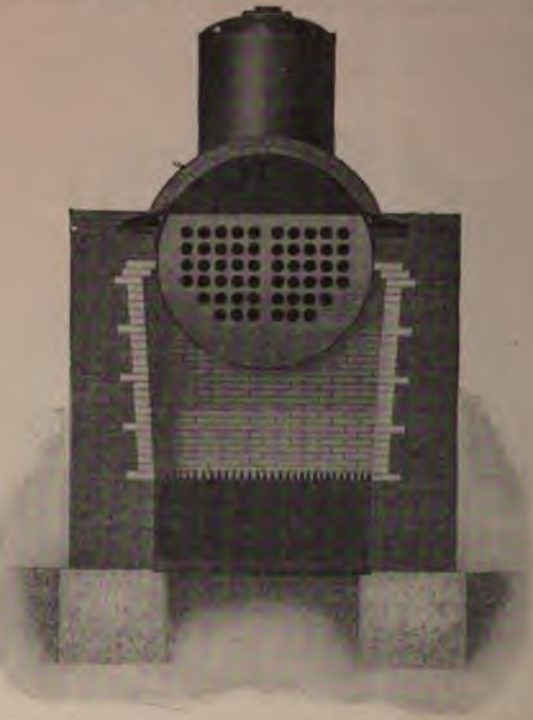

FIG. 80. — Section through Furnace of Return Tubular Boiler.

SPECIFICATION FOR BOILER SETTING IN THE CENTRAL HEATING STATION OF THE UNIVERSITY OF WISCONSIN

A specification for the setting of boilers is illustrated in the appended example of a central heating station, which includes two 350-h.p. Babcock and Wilcox water-tube boilers equipped with Roney stokers. The character of the brick and the method of setting demanded by the consulting architect and the engineer, Mr.

Arthur Peabody and Mr. H. J. Thorkelson, of Madison, Wis., is instructive. For instance, the fire brick should be of good quality; the arches to be of Woodland, the lower side walls of Laclede crown, the upper side walls of Sterling crown and the second pass of Ajax fire brick. Wherever common brick are used, they should be of best quality hard-burned brick, and in this particular specification the face brick are a good quality of repressed brick. The common brick are laid in a mortar made up of equal parts of clean sand, fresh lime and Portland cement. The fire brick should be laid in a batter of fire clay and rubbed into place and the joints made as close as possible. No trowels should be used in the fire-brick work.

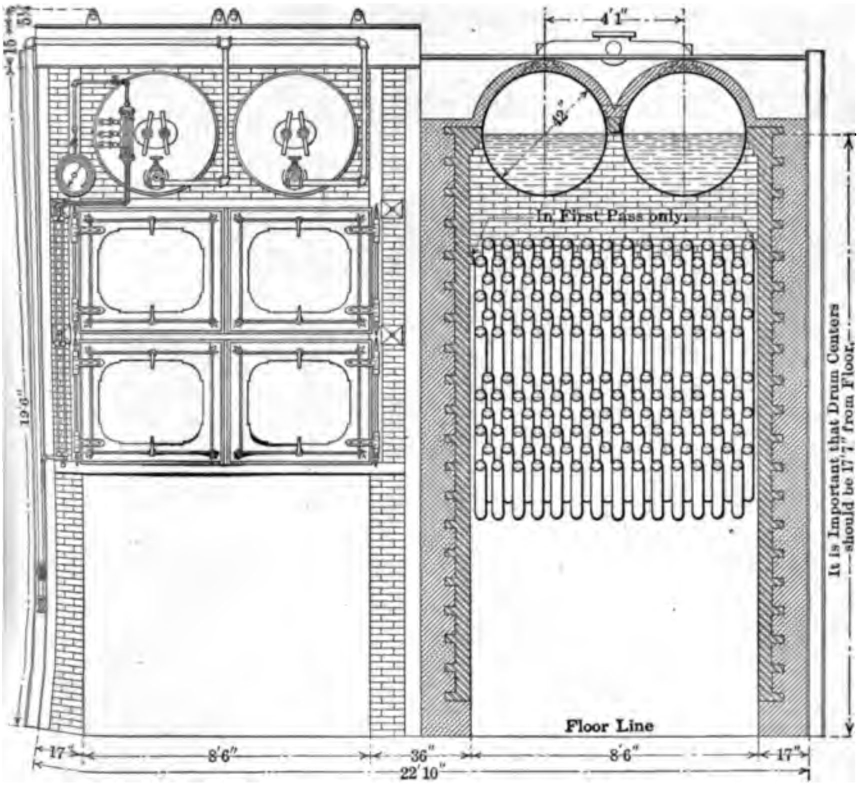

FIG. 81. — Illustrating Babcock and Wilcox Boiler Setting.

1. Bids. — Bids will be received for the entire brick setting of two 350-h.p. Babcock and Wilcox Company's water-tube boilers and Roney stokers. These boilers and stokers will rest upon the concrete floor of the Central Heating Station of the University now completed.

2. **Position.** — These boilers will be set in a battery of two each as shown on the accompanying drawings of the Babcock and Wilcox Company and the Westinghouse Machine Company. The drawings show the manner in which the boilers shall be bricked in and the parts that shall be lined with fire brick.

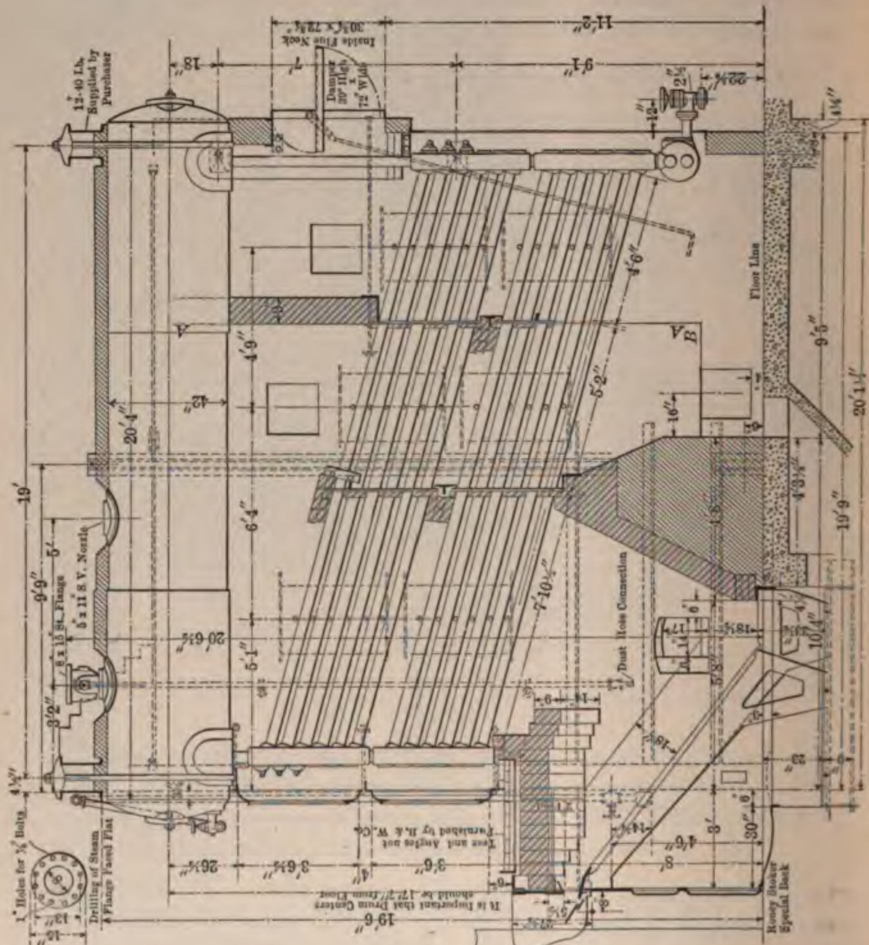

FIG. 82. — Section showing Boiler Setting.

3. **Arches.** — The arches shall be constructed of Woodland fire brick of the best quality. The brick shall be set with a 2- by

4-inch face to the flame. Each ring shall be bonded to the adjacent rings in the best possible manner. It will be necessary to use the standard 2-inch by 4½-inch by 9-inch and 2-inch by 6-inch by 9-inch brick; also 2-inch by 4½-inch by 9-inch and 2-inch by 6-inch by 9-inch wedge brick in this work. The contractor shall construct the centers for this work, but when the work is finished they shall become the property of the University. Build 9-inch fire brick and common brick relieving arches as shown on the drawing.

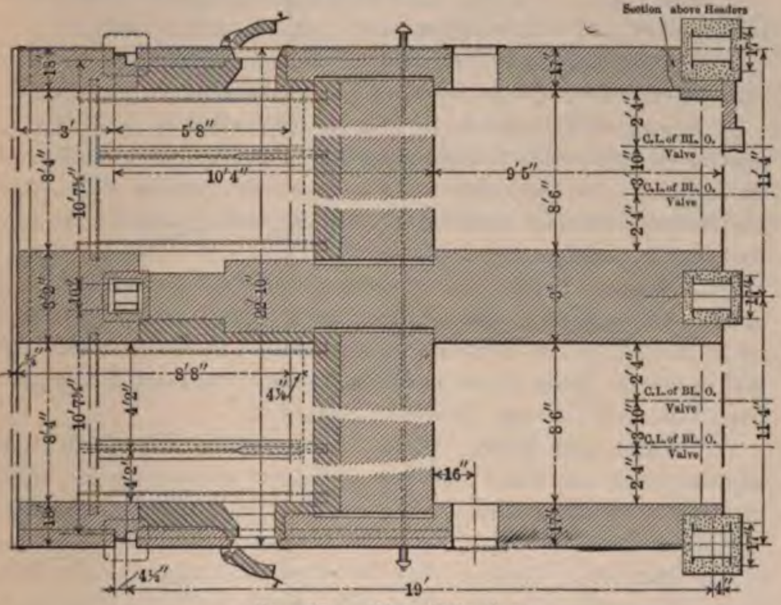

FIG. 83. — Plan of Setting.

4. Side Walls of Furnace. — The side walls of the furnace from a point 3 inches below the top of the side bearer to the line of the lower tube, together with the entire face of the bridge wall exposed to the fire, shall be lined with 9 inches of the best quality of Laclede crown fire brick set with 2- by 4½-inch face to the flame.

5. Side Walls' Front Pass. — From the line of the lower tubes to the drums and the entire surface above the tube as far back as the hanging bridge shall be lined with 4 inches of the best quality of Sterling crown fire brick. These brick shall be set with the 2 by 9 face to the hot gases and shall be bonded to the common brick with full header courses every fourth course. Build a 9-inch hanging bridge wall as shown on the drawings of Sterling crown fire brick.

6. **Second Pass.** — From the line of the upper tube in the second pass to the line indicated on the drawing the boiler shall be lined with 4 inches of Ajax fire brick set in the same manner as specified for Sterling crown brick.

7. **Fire Clay.** — All clay used on this work shall be of the very best quality and well tempered and mixed to a thin batter.

8. **Special Blocks.** — The space at the sides of the front headers shall be closed by special fire-brick blocks made to fit the headers.

9. **Laying of Fire Brick.** — The fire brick shall be laid only by masons experienced in fire-brick work. None other will be allowed on the work. All fire brick shall be dipped in a batter of fire clay and rubbed into place, making the closest possible joints. Trowels shall not be used on fire-brick work.

10. **Common Brick.** — The common brickwork shall be built of the best quality of hard-burned brick, samples of which shall be submitted to the architect for approval. These brick shall be laid in mortar made of one part sharp, clean, bank sand, one part fresh lime and one part Portland cement.

11. **Water and Sand.** — The University of Wisconsin will furnish water and sand for this work, but the contractor shall carefully screen the sand. All other materials shall be furnished by the contractor.

12. **Cement.** — Cement shall be Eastern Atlas, Lehigh, Medusa, Universal or other well-known brand of Portland cement, accepted by the architect. All cement shall be subject to test by the architect before being incorporated into the work, and must come well within the standard specifications of the American Society of Civil Engineers.

13. **Facing Brick.** — The exterior walls of the furnace back to the front boiler columns shall be faced with the best quality of hard-burned, vitrified pressed brick, standard size of a strong buff color. These brick shall be similar in every way to the No. 61C repressed brick made by the Ayer McCarl Company of Brazil Indiana, now used in the facing of the boiler room. They shal be laid with pressed-brick bonding headers every fourth course The courses shall be kept plumb, level and straight, and the joint of uniform size. The color of the mortar shall match the morta

used in facing the boiler room. All other exterior walls shall be faced with selected common brick laid with close joints.

14. **Doors, Braces and Anchors.** — Build in all doors, braces, anchors, etc., furnished by the boiler and stoker companies.

15. **Foundations for Stoker Engines.** — Build pressed-brick foundations for one small stoker engine. Furnish and build in anchor bolts three-fourth inch diameter extending through the floor with cast-iron washers on bottom.

Finally. — This contract contemplates and comprises a perfect and complete job of boiler setting and anything necessary to that result is hereby included the same as if particularly mentioned, described and detailed upon the plans and details. When the work is completed the contractor shall remove from the premises all tools, débris, machines and apparatus of every sort belonging to this work, leaving the premises free and clear from everything of the kind.

CHAPTER XI

DIRECTIONS IN CONSTRUCTING FURNACES

THE USE OF REFRACTORY MORTARS AND PAINTS

Some Laws of Furnace Construction. — In constructing furnaces with refractory materials the laws governing the erection of brick and stone buildings should be observed. As the size of the furnaces is increasing from year to year, it seems as though economy and safety would dictate the use of larger forms than the standard brick, just as freestone forms the foundation and often a part of the superstructure of edifices. The furnace, it would seem, would be stronger and a more homogeneous compact mass, with fewer joints to weaken the wall and allow the attacks of metals and slags. But our hands are tied to some extent by the fact that it is not easy to prepare large forms which will mix, knead, dry and burn as evenly as the smaller bricks. The drying and burning of large shapes is more costly if it is done as thoroughly. If the larger shape is burned to the core, considerable time, patience and money must be expended. Then again the furnace made up of the small-brick units is more elastic and withstands the alternate expansion and contraction of the heated and cooled body better than it would were it built of larger blocks. Again, the mason likes the standard size and claims that cracks formed in the larger blocks are less easily controlled than those which form in the joints, i.e., in the mortar, in the small-brick wall.

The furnace should always be built with due regard to the modulus of expansion or contraction of the material used. For instance, silica walls, roofs and hearths expand on heating and even when cooled retain some of their growth, whereas fire-clay brick generally expand slightly in the heat and contract to less than the original dimensions when cooled. In ordinary furnaces the furnace may be held to size by tightening or slackening the bolts or trim buckles in the long and cross-tie bars. With arched roofs particular care should be observed. I have seen a magnesia roof crush to pieces in expanding on its first heat, and a fire-clay roof fall after a short campaign on account of lack of proper supervision. Then again the "heating up" of a furnace, especially of a large reverberatory, must be done slowly and gradually. A long copper reverberatory furnace in which I was interested was warmed in the usual way by burning, at the beginning of the campaign, a number of wood fires on the hearth. These were not evenly spaced, nor were there sufficient of them. Before the firebox gases were started the furnace was already damaged. The roof, throughout the whole length, waved up and down in a remarkable way. The usual care had been observed in loosening the expansion joints in the tie bars so that the arch of the roof had raised uniformly; nevertheless the life of that particular furnace was short. The damage done to a hearth is less readily seen and only makes itself felt by dropping a bath of metal or matte, at a time when no suspicion of its weakness is entertained.

When using silica, magnesia and chrome bricks especial care must be observed on account of their peculiar physical construction. They all expand considerably under heat, and all spall when subjected to sudden changes of temperature. All furnaces in which these materials are employed should be warmed and cooled very slowly. Magnesia bricks last longer if they are surrounded with water jackets. The cool magnesia is much more resistant to the action of slag and heat than the hot material.

From 250 to 350 pounds of fire clay or silica cement are enough to lay 1000 bricks. The joints may be made larger in using silica bricks, and more mortar used than is advisable in the case of fireclay bricks which do not expand much and consequently will not fill any interstices which the contracting mortar may leave when heated. It is good practice to always use the same refractory for the ground mass of the mortar as that which composes the wall, roof or hearth of the furnace.

For estimating on fire-brick work the following figures may be used:

1 square foot 4½-inch wall requires 7 bricks.
1 square foot 9-inch wall requires 14 bricks.
1 square foot 13½-inch wall requires 21 bricks.
1 cubic foot brickwork requires 17 9-inch straight bricks.
1 cubic foot fire-clay brickwork weighs 150 pounds.
1 cubic foot silica brickwork weighs 130 pounds.
1000 bricks (closely stacked) occupy 56 cubic feet.
1000 bricks (loosely stacked) occupy 72 cubic feet.

For estimating on red brickwork it is safe to figure on 9 cubic feet of sand and 3 bushels of lime for laying 1000 brick.

1. ft. =
4c/-

All refractory bricks should be stored in a dry place. With scarcely an exception all kinds are damaged by contact with damp air. Magnesia bricks may be destroyed entirely since magnesia forms the hydrate very easily and in "blowing," the brick crumbles. In shipping over the high seas or to moist climates the bricks should be packed in boxes and stored in a dry place. Fire-clay brick suffers from freezing and all refractories should be kept at a moderate temperature the year round. In storing raw materials it is well to remember that natural rock, like granite, expands on weathering due to some disintegration, quartzite materials swell and break and fire clay becomes plastic and is liable to deteriorate.

Refractory Mortars, Cement Facings and Coverings. — The mortar serves the purposes of filling the joint cracks between the bricks, of holding the wall or roof firmly together and of protecting these most vulnerable parts in a furnace wall or roof from the attacks of the slag. It must have the same refractory quality as the lining or roof. The difference in the quality of the mortar and furnace refractory lies chiefly therein that the former may be used raw or in a half-prepared condition and may be burned and fritted thoroughly when in position in the furnace. Accordingly the mortar should have as high a temperature of fusion as the bricks employed. Yet it must sinter to a dense mass, and not "blow" or contract. It is necessary to practice considerable self-restraint in selecting a mortar which will fulfil these conditions, and not endanger the length of the life of the furnace by using any mortar which may be at hand. It is better to import from a considerable distance to a locality devoid of good refractory mortar-making material than "to scuttle the ship for a ha' puth of tar." It is perhaps in boiler settings that many evidences of this negligence are found.

The four ordinary varieties of mortar are: (1) Lime mortar, (2) fire-clay mortar, (3) common clay mortar or mud and (4) cement. The lime mortar, made of lime and sand, may not be used where it will be exposed to heat; it bonds very strongly when kept cool and should be used where strength is desired. The fire-clay mortar is used with most refractory fire-clay brick.

The fire-clay mortar proper may be divided into two classes, known as natural and artificial. The first class includes the argillaceous sandstone which occurs in all deposits of fire clay. Those kinds have particular value, which contain a large excess of silica and some moderate quantities of fluxing agents. They must also work easily with the trowel and burn to a dense sinter between the bricks. The artificial mortar is made from grog or chamotte (ground brickbats, tile, retorts, etc.) and mixed with a refractory clay free from sand. This mixture should have approximately the composition of the brick which it is to bond.

Besides the mortars named many other mixtures are used for different refractory materials; generally they are made of the same material as that of the refractory.

Care must be taken that the mortar does not enter into chemical combination with the bricks, and it should not actually fuse at the temperature at which the furnace or vessel is employed. It should burn at the temperature employed to a sinter and knit the whole structure together. Joints should be eliminated whenever possible, and very little mortar should be used between the bricks.

For many vessels, in which there is little physical or chemical action on the wall, such as in boiler settings, the mortar may consist of a mixture of ground clay and sand.

Generally, however, an addition is made of some of the refractory composing the walls. Then in order to make the mortar bond and point well, some plastic clay should be admixed. The whole must be ground fine and well packed for transportation or storage. The various kinds of refractories need, however, different mortars. Dinas and silica bricks are laid in a mortar of fine-ground quartz and good fat clay; quartzite and lower-grade silica bricks may be bonded with a mixture of fine sand, ground chamotte or grog and plastic clay. Fire-clay bricks require fine-ground chamotte and plastic clay with sometimes an addition of ground quartz or chamotte made from broken quartzite and silica bricks. Magnesia bricks are best laid without bond, wherever possible, that is, skin to skin. When a mortar must be used, the best of all the many mixtures proposed is a finely ground burned magnesia and linseed oil. Water must not come in contact with burned magnesia brick or it will at once become hydrated and weak. Charcoal and coke bricks are set with a mortar consisting of 2 parts coke dust and 1 part ground clay. Dolomite bricks are dipped in tar and laid close, the joints then burned tight.

For closing tap holes, plugs of plastic clay mixed sometimes with coarse chamotte of fire clay or even of silica brick are used. Sometimes coke braize is intermixed. For daubing and quick repairs a water-free mixture of chamotte and plastic clay may be used. In furnace heat a mixture of chamotte, clay and graphite, or of magnesia, fire clay and water glass (52°) sets quickly and holds well.*

The clay mortars should be spread in flat boxes and digested with water for several days. The old supernatant water should be poured out every few days, fresh water added and the whole mass stirred up to form a good paste.

All tar mortars should be used as hot as the workmen will stand. The masons should wear good gloves during this trying stage of brick laying. Joints should not be, at the most, more than $\frac{1}{4}$ inch thick. Mortar used in furnaces should be as thin as possible and have approximately the consistency of cream. Bricks with large uneven surfaces should be ground by rubbing on one another. The bottom bricks are covered with a homogeneous mass of thick mortar. The upper bricks are then laid on, pressed firmly down, and tapped backward and forward to make them lay as tightly together as possible. The excess mortar is thus squeezed out and wiped off the joint. The outer joints are carefully pointed with a minimum amount of mortar. The fresh brickwork is gradually dried by careful warming before being subjected to the high temperatures and the weight of the charge. For facings and breasts, mixtures of water glass with clay, magnesia or asbestos are favored, while borax, boracic acid, salammoniac, linseed oil and other materials are often used as bonds.

In coating steel or other furnaces to render them fireproof the *Mining and Scientific Press* (April 21, 1911) recommends to first brush the brickwork with a solution made by boiling 1 pound each of silicate of soda and alum in 4 gallons of water and then follow immediately with a well-mixed composition of silica 50 parts; plastic fire clay, 10 parts; ball clay, 3 parts.

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* The mixture of fire clay and magnesia with from 10 to 20 per cent of water glass is most satisfactory for plugging runaway lead or matte taps, for repairing breasts and for fettling and packing.

Rope may be made fireproof by the following solution: Ammonium chloride 15 parts by weight; boracic acid, 6 parts; borax 3 parts, and water. A mixture of water glass and asbestos with sometimes some admixed magnesia, heavy spar or fire clay is used for painting the interior of flues. Various batches of asbestos and magnesia and other asbestos mixtures are used as fireproof coverings.

Mixtures of tar and burned magnesite, tar and chromite, of tar and fire-clay grog and of tar and sand are all used as protective paints and coverings against acid, hot fume, gases, and molten products. The acidproof glazes are described in Chapter IX, pages 185 to 187.

Soapstone has great heat-resisting qualities and is a good electric insulator, but it can only be used where the volume of the mass used is not prohibitive. Mica is also resistant to heat, makes a good packing and provides excellent dielectric resistance. The disadvantage of its use lies in its friability.

Refractory Cements. — These are often not strictly refractory or highly infusible but serve a good purpose in filling small cracks and interstices in refractory or fireproof brick and ware. Among these useful cements are argillaceous sandstone and the so-called "plastic dinas" of which three samples are submitted.*

Analysis by	a Bischof.	b Seger.	c Bischof.
SiO_2	87.48	87.89	86.42
Al_2O_3	4.66	7.17	9.33
FeO	2.62	0.82	0.86
CaO	1.08	0.95	0.34
MgO	....	....	0.22
Alkali	....	....	0.37
Loss on ignition	3.96	3.04	0.40
	99.80	99.87	97.94

This does not change its volume or crack at medium temperatures, is plastic and easily moulded.

Another is composed of loam sand and powdered glass in varying proportions. The so-called Holland cement contains large quantities of gypsum.

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* *Handbuch der gesammten Thonwaarenindustrie*, Kerl, p. 913.

The water-glass mixtures particularly water glass and magnesia, and water glass and heavy spar are used as cements. The sandy Hessian clays and sticky sands are used with advantage for repairing furnace walls.

Siemens recommended the blowing of sand and ground quartz against the weak spot in a furnace for the same purpose. Sand admixed with clay is used to fettle and repair the hearths of copper reverberatory and other furnaces. The sand is thrown with the shovel against the hot wall, where it frits at once forming an adhesive coating.

Asbestos cements composed of asbestos bonded with fire-clay magnesia and other refractory materials are used widely in pointing and joining first-class fire brick. The H. W. Johns-Manville Company market various kinds, of which from 250 to 350 pounds are required to set up 1000 standard fire bricks. This company has developed the application of asbestos and various mixtures and batches for manifold purposes. Among these is a fire-brick coating, of which 50 pounds is required to face 1000 standard fire brick. They also make insulating and building materials, using amongst other ingredients wood pulp, hair, rubber, and various textiles, gypsum and alkaline earths. Thus they have exploited asbestos covering for pipes and boilers, steam packings, stucco, wood, paint, retort cement, cold-storage insulating materials, magnesia pipe, lagging, plaster, rubber cloth, rubberoid roofing and various kinds of fireproof materials. Their standard mixtures which are the most refractory and useful are made of asbestos and magnesia. Special mixtures are made for use at different temperatures, since it has been found that these asbestos mixtures should commence to sinter and slag at the temperature employed in order to prevent the physical deterioration of the asbestos.

Insulation of Furnaces. — An air space in the divided wall, under the hearth or in the roof of a furnace, is often a poor insulator. Once the interior part of the wall attains a high heat, the air will conduct it across to the outside wall quicker than almost any refractory material of non-metallic character. Coke braize, ashes and asbestos are much more satisfactory. One of the asbestos-magnesia, or asbestos-clay batches, made especially for the industry, answers better than any other material. Many fire-refractory materials and brickwork form minerals with a high modulus of expansion at high temperatures. Those which become physically weakened in expanding, like magnesia, must be water-jacketed in order to preserve them from their own physical disintegration and the chemical attacks of slags and metals to which they are more exposed at high temperatures. Waterjacketing robs the furnace of some heat. This is less than might be expected, since the heat conductivity of the wall is reduced by cooling. Yet this drawback must be taken into consideration when selecting the refractory material. A reasonably close estimate of the heat lost by water cooling may be made by measuring the temperature of the ingoing and outflowing water and the quantity of water passing through the jackets, calculating the calories absorbed therein in 24 hours and comparing this quantity with the total developed in the fire box in the same time.

To make a comparison, however, of the heat lost in watercooling and that which would be lost without cooling, reference must be made to the methods of determining the flow of heat through furnace walls.

Furnace Efficiency. — Modern practice in the metallurgical and chemical industry has proved the advantages and the economy of working with large furnaces. Less attention has been given to the matter of the form which will produce the best results and to the material which will conserve the heat developed in furnaces. Every line of the furnace has been made with a view to realize the heat in the fuel gases, without much regard to the distribution and conservation of that energy. In the reverberatory furnace this heat comes from the orthodox fire box situated at one end, or from producer gas or oil passed in through the two end walls. In the case of the blast furnace the economy of the furnace of large content has been demonstrated. In the form of the furnace we have been bound by the measure of the center line from the sides, at which the blast from the tuyeres may be effective. In regard to the material composing the walls, we have always selected the most easily handled refractory material of moderate cost.

Metallurgical science has not aided the practical engineer to solve these problems; practice has outstripped theory. Now, however, we may question with some grace the wisdom of retaining the present forms and materials. One of the sources of great loss of heat is its flow through the furnace walls and roof.

Now the quantity of heat lost through a wall or roof depends:

(1) On the thickness of the wall, r, on the area of the wall or of that part of the wall under measurement, namely, A.

(2) On the difference in temperature of one side of the wall T_1 and of the other side T_2.

(3) On the modulus of heat conductivity possessed by the material composing the wall.

Then Q (the amount of heat lost in one unit of time)

$$= K\frac{(T_1 - T_2)}{r}A, \text{ or } Q \text{ in } t \text{ units of time} = K\frac{T_1 - T_2}{r}At.$$

All these are measurable factors with the exception of K. K is written down, happily and irresponsibly, in books of tables as a constant. Fire brick, for instance, we find has a value for K of 0.7 kg.-cal. sq. m. hour ° C.* This figure means little to the constructing engineer. The modulus of conductivity K of fire brick, as a matter of fact, varies with different brick and depends:

(1) On the chemical composition of the material of which the fire brick is composed.

(2) On the porosity, permeability, size, character and number of grains and pores contained and other physical properties.

(3) On the temperature at which the brick is burned.

(4) On the temperature obtaining in the furnace where used.

(5) On the character of the insulating material outside the furnace, if any.

(1) In a series of determinations, S. Wologdine found the value of K to be as follows:

In sample of fire-clay brick burned at 1050° $K = 1.32$.
In sample same fire-clay brick burned at 1300° $K = 1.81$.
In sample silica brick burned at 1050° $K = 0.71$.
In sample same silica brick burned at 1300° $K = 1.12$.
In sample carborundum burned at 1050° $K = 5.22$.
In sample same carborundum burned at 1300° $K = 8.32$.
In sample magnesia brick burned at 1050° $K = 2.08$.
In sample same magnesia brick burned at 1300° $K = 2.35$.
In a sample of kieselguhr $K = 0.64$.
In two samples graphite $K = 8.64$ and 9.0.
In a sample bauxite burned at 1050° $K = 1.11$.
In another sample bauxite burned at 1300° $K = 1.19$.

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* Landolt and Boernstein, and *Ingenieurs Taschenbuch Hütte.*

(2) The conductivity varies with the porosity. It is therefore a function of the air enclosed in the pores of the brick. This is exemplified in the following table:

Material.	Porosity per cent.	Permeability in litres per hr. per sq. m.	Conductivity kg.-cal. per hr. per sq. m.
Fire brick:			
RB-5	29.44	37.84	1.25
RA-5	30.85	14.72	1.32
RB-9	30.2	106.2	1.50

Points (3) and (4) have been proved in the discussion of (1).

(5) Messrs. Ray and Kreisinger* have shown that the loss of heat through the fire-clay brick side walls of a furnace is 1.3 that through the roof of the same thickness. They have also shown that an air space between a divided wall or fire bridge of a furnace conducted heat more rapidly than the fire brick itself and many times as much heat flowed through it as through a similar thickness of asbestos. For bodies under a temperature of 625° C., it is true, the air space does act as an insulator, but the higher the temperature the better conductor it becomes and the more heat it loses. So much for the loss of heat through walls. The material which has the lowest value for K is kieselguhr which may not be used on account of its lack of strength in brick or other form. Fire clay is the next best.

Our object always is to make Q as small as possible in the equation:

$$Q = K\frac{(T_1 - T_2)}{r}A.$$

This may be accomplished either

(1) By making K low. K may be low by using a material of low heat conductivity such as kieselguhr or fire-clay brick. Let us use, then, fire clay. But suppose the operations in the furnace require magnesia. Then make the K of magnesia as low as possible by keeping the material cool. That is to say, water jacket the magnesia wall or hearth.

(2) By making the difference between the outside and inside temperatures of the wall or roof, namely, $T_1 - T_2$, as small as possible. This can only be done by heating the outside of the wall T_2 by such mechanical means as passing waste gases about it.

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* Bulletin 8. Bureau of Mines.

(3) By making A or the area of the walls and roof relatively small and r, the thickness of the walls, relatively large.

In the ordinary rectangular reverberatory furnace we are tied, to a certain extent, in that the strength of the furnace demands a certain ratio of r to A. We cannot make r indefinitely large, on account of the high cost of furnace brick and material. But we can evolve and select a form of furnace in which the ratio $\frac{A}{r}$ will be the smallest possible to effect the completion of a certain amount of work. It is plain at once that the furnace of rectangular horizontal section is one which is very far indeed from fulfilling this condition. The sphere is the most ideal form, followed by the cube.

Considerations (1) and (2) suggest immediately that we should insulate or heat the outside of fire-clay roofs, walls and hearths, and water-cool magnesia when used in furnaces.

We have been doing this to some extent in practice. The roofs of furnaces are often protected by a covering of ashes, coke braize or sand. Magnesia walls are generally jacketed because it was soon found that they spalled less and were more resistant to the corrosive action of slags and oxides. These magnesia walls were sometimes ruined when they were not water cooled; because their porosity and permeability was increased at high temperatures. Hence the modulus of heat conductivity was increased and therefore also Q, or the flow of heat, became greater, and further, the increased porosity allowed the slags to penetrate the mass and corrode it more quickly.

An important question is, how much heat may we save by methods of reducing Q, by keeping K low, and by making $T_1 - T_2$ small, by insulating or by heating the outside walls. It is impossible to state this definitely. We know that a blast furnace loses about 4 per cent of its total energy by radiation and flow through walls. Reverberatory furnaces lose a larger proportion. For example, let us consider the loss of heat by flow through walls and roof of a copper reverberatory furnace 30 meters (100 feet) long, 6 meters (20 feet) wide and 1½ meters (5 feet) in average height from the top of the bath to the roof, or 2 meters from the hearth to the roof. Let us consider the hearth or bottom perfectly insulated. Let the roof be 25 centimeters (one brick) and the sides 1 meter (3 feet 3 inches) thick, with the inside temperature at 1400° C., and the outside of the walls 100° C.

Suppose the fire brick has a modulus of conductivity on an average, considering temperature and slight variation in chemical and physical composition, of 1.2 kg. cal. hr. First consider the loss through the walls.

Then,
$$Q = K\frac{T_1 - T_2}{r}A.$$
$$= 1.2 \times \frac{1400 - 100}{1}((2 \times (30 + 6)) \times 2).$$
$$= 224{,}900 \text{ kg. cals. lost per hour.}$$

Now such a furnace in treating copper ores would smelt about 10 tons an hour with a coal consumption of about 2½ tons. Suppose the coal has a calorific value of 3000 cals. This means one ton has 3,000,000 kg. cals. and 2½ tons have 2½ × 3,000,000 = 7,500,000 kg. cals. Therefore, the heat lost in the walls is about 3 per cent. Under some conditions the walls would be about half a meter thick. Then $Q = 449{,}800$ kg. cals. and the heat loss becomes 6 per cent.

In the roof the loss will be, supposing the outside temperature is 200° C., and the thickness of the roof 0.4 meters:

$$Q = 1.2\frac{1400 - 200}{0.4}(30 \times 6).$$

This supposes the roof to be flat. But it is an arch. This difference offsets the relatively smaller quantity of heat conducted through the roof as determined by Ray and Kreisinger.

Therefore $Q = 1.2 \times 1200 \times 180 \times \frac{10}{4} = 650{,}000$ kg. cal. per hour, which is 9 per cent of the total heat developed in the furnace. The total heat lost in this case is from 12 to 15 per cent. The greatest loss is in the roof. It is a question whether this heat could be preserved by the simple means of insulating with ashes, sand, etc., or, better still, by one of the asbestos mixtures sold in the trade; or whether the increased life of the material in roof and lining which is cooled on the outside would not counterbalance any saving in fuel energy which might be obtained by insulating, and therefore endangering the life of, the refractory material.

Clement and Egy [*] determined the heat lost in the walls of a 210-H.P. Heine boiler, which contained 364 square feet of surface and were 20 inches thick. The average temperature of the inside of this area was 1400° F. (755° C.), and of the outside 150° F. (65° C.). The value of K for the fire brick was 0.92.

Then $Q = 0.92\,\frac{760 - 65}{\frac{20}{12}} \times 364$ in kg. cal. per square foot per foot hour 1°.

To change to metric measure,

$$Q = 0.92\,\frac{755 - 65}{\frac{20 \times 2.54}{100}} \times \left(364 \times \frac{929}{10{,}000}\right)$$

$= 43{,}400$ kg. cal. per hour or 172,000 B.T.U. per hour, which is 1.6 per cent of the total heat generated.

Shape of Furnace. — It is apparent that by making r infinitely large in the forgoing discussion we could have made the loss of heat Q very small. It is equally true that by making A very small at the same time that $(T_1 - T_2)$ is kept within reasonable limits we reduce the loss. Supposing we keep $T_1 - T_2$ constant and K constant, how can we get the lowest value for Q? If we work with a large furnace we make A relatively small. That is the first solution of the question of economical operation of furnaces.

Let us then ask in what shape of furnaces can we make A smallest while keeping r relatively large? Naturally in a sphere. A cube would come next, and our usual shape, a long narrow and shallow furnace, would inevitably prove very uneconomical.

Mr. Carl Hering [†] has calculated tables and drawn curves showing the variation in the loss of heat in bodies of all shapes with the different thicknesses of the furnace walls. He compares especially spheres, cubes and cylinders. With the curves showing the loss of heat as a function of the thickness of the walls for spheres, cubes and cylinders, Mr. Hering shows that, for a given interior volume and the same relative thickness of walls, a furnace of spherical form loses less heat by conduction than a cubical furnace.

We use the present type of reverberatory furnace because the heat from the fire box may be realized in this form to the greatest possible extent and because of the difficulty of constructing an arch of more than 20 feet base, which will stand the severe strain to which the brickwork is subjected in heating and cooling. Nevertheless it would seem as though the furnace approaching the cube, namely, with square horizontal section, might effect some economy, provided its length was not less, or not much less, than the present measurement of such furnaces as the Anaconda reverberatories and that it could be safely constructed with a long low-arched roof. This would probably be a more difficult problem than that of the realization of the calorific value of the fuel, for the present length of the furnaces might be taken as the one side of the square, the present width of the furnace increased, along with the length of the line of fire boxes, which would, of course, have their working doors along the whole length of one end of the furnace. With every foot increase in width it would seem, on theoretical grounds, that there might be a conservation of the heat now lost through the furnace walls. This method of construction is much more feasible to-day, since the process of "claying" the side walls by hand has been abolished in many works.

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[*] *Bulletin* No. 36 University of Illinois, 1911.

[†] *Metallurgical and Chemical Engineering.* Page 97 (February) and page 159 (March), 1912.

CHAPTER XII

REFRACTORY HOLLOW WARE

Capsules, Crucibles, Retorts and Muffles. — This ware may be divided into three classes:

(1) Those which serve to impart the heat to, but protect from gases, the actual vessel containing the fusion. Such ware includes muffles.

(2) Those in which the fusion is directly conducted in the vessel which is exposed to the fire gases; crucibles are of this class.

(3) Retorts and muffles intended for distillation and used chiefly in the zinc industry and in gas works.

Classes (1) and (3) must be made to withstand sudden changes in temperature. Quite especial care must be taken in making the gas retorts, since they must withstand the changes of temperature incidental to the drawing and feeding of the charges. The distilling vessels used in the metallurgical industry must be able to resist the attacks of the metal fume. Class (2) must, in addition to possessing the qualities demanded of (1) and (3), be physically strong to support the fused or boiling mass inside, and chemically constituted to resist the action of slags, oxides and metal or metallic combinations. To satisfy these demands, clays are used which combine a sufficient degree of refractoriness with the capacity for bonding a mass of well-burned and dense fire-clay grog. Since the addition of grog raises the temperature at which the clay burns to a dense mass, the burning point of the clay selected should be relatively low, that is, about Seger cone 1 to 3 (1150° to 1200°).

Saggers

Capsules. — Capsules used in ceramics are open dishes with perpendicular sides, in which crockery, porcelain and stoneware are set before being placed in the burning furnace. The capsules serve the purpose of protecting the ware from the influence of the fire gases and ashes.

The capsules should not contract when fired, or crack at sudden changes of temperature. They must be inexpensive and last many campaigns. They must be strong to bear the weight of the pile of upper capsules and their contained porcelain or stoneware. The clay of which they are made must be free from pyrite, gypsum, or gas-making or fluxing constituents; it must be homogeneous and make a smooth and even surface. The better made the capsules, the cheaper will be the ultimate cost of the stone or porcelain ware. The sides are made one-half to one inch thick, but the thinner are preferred. The clay chosen must be sufficiently plastic to absorb a considerable quantity of grog made from broken capsules. Generally two or three clays are mixed to obtain the desired properties. Some mixtures are:

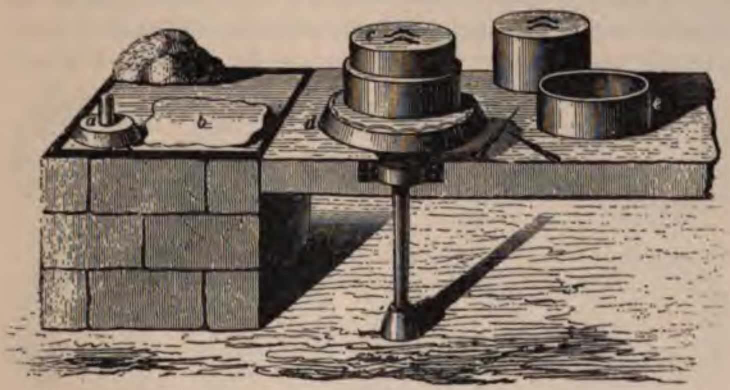

FIG. 84. — Preparation of Capsules.

(1) Two parts lean clay, one to two parts grog.

(2) Two parts clay, four parts raw kaolin, three parts grog.

(3) The mixture used at Sèvres consists of two parts plastic clay with three parts capsule grog. The clay is dried and ground, and then mixed with the requisite quantity of grog and raw kaolin, soaked and mixed. The capsules may be moulded with a pattern (*c*) or on a wheel (*d*); the resulting capsule is represented by *e* (Fig. 84). After they are formed the capsules are dried in racks. When thoroughly dry they are burned in the ordinary porcelain or biscuitware furnace.

Muffles. — Muffles are made in many shapes and sizes to serve various purposes in the world of ceramics, of metallurgy and of industrial chemistry. They are used like capsules and the vessels to be heated are placed in them; thus they are distinguished from retorts which are shaped in a similar fashion, but differ in that they are charged directly with the material to be heated or fused. Cross-sections are rectangular with the top slightly arched, semi-cylindrical with flat bottom, or semi-elliptical with the long axis along the bottom. The temperature to which they are exposed and the changes and numbers of heats demanded of them vary in the different industries. In metallurgy the claims are most severe: they must stand temperatures of 1200° and 1300° C. and sudden changes. In ceramics they are used as a rule for holding ware which burns at a low temperature; considerable heat is required, however, when enamelled iron ware is burned in muffles. Sizes vary from a width and height of a few inches to several feet, and the thickness of the clay from one-third inch up. Generally it is between one-half and one inch.

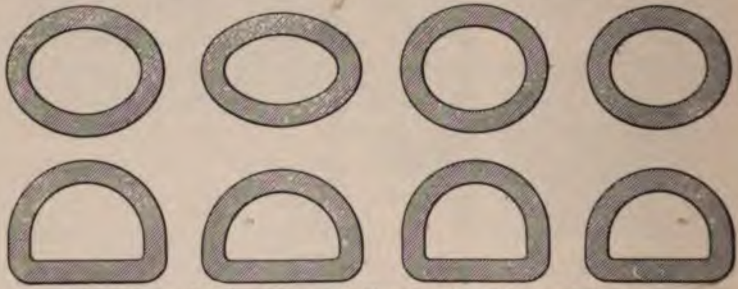

FIG. 85. — Sections through Shapes of Muffles and Retorts.

Mixtures for muffles are made generally of about one part of plastic clay to one or two of old muffle grog, the size of the grain of the grog increasing the size of the muffle. Kerl prescribes for the German muffles the following mixtures:

(*a*) For large muffles: one part Westerwald clay,* one part sand-bearing clay, four parts grog (fine and grain from $\frac{1}{10}$ inch to $\frac{1}{5}$ inch).

(*b*) Eight parts Halle clay,* seven parts grog (grain of $\frac{1}{10}$ inch), two parts grog (grain of $\frac{1}{20}$ inch).

(*c*) For smaller muffles: one part Waldenburg clay,* one part grog (grain of $\frac{1}{10}$ inch).

(*d*) Two parts clay from Halle,* one part grog (grain of $\frac{1}{25}$ inch), one part sawdust.

The sawdust makes the mass somewhat porous and therefore resistant to changes in temperature.

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* A plastic refractory clay.

The moulding of the muffle is often done by hand. The clay mixture is kneaded and flattened. It is then tamped into a wooden form; the inside measurements of this represent the outside dimensions of the muffle. After the mass is tamped in to make the required thickness the inside is smoothed, the wooden mould taken apart and removed. Small muffles are sometimes formed round a cone, or they may be made by pouring the clay into a hollow mould of the shape of the muffle or they may be squirted through a die in a combined pug and auger machine. After moulding the muffles are dried and burned. For patching muffles and pointing the interstices between them and the brickwork of a furnace, mortars of fire clay and asbestos, of plaster fire clay and grog and of fire clay alone may be used.

Crucibles. — Crucibles must combine density with qualities of resistance to fire and chemical influences of oxides, slags, sulphides and metals, and mechanical strength to bear the pressure of the heated charge. They should not crack or break with sudden changes in temperature. The industry of making crucibles is large and increasing. The steel, alloy and electrochemical industries call constantly for larger quantities and better grades. The assayers', jewellers' and chemists' needs are constant; in the ceramics and silver- and gold-refining industries larger quantities are used.

It is not remarkable then that crucibles are made of absolutely proven refractory materials to serve manifold and various kinds of purposes. The fire-clay crucible made in all sizes is still the favorite, followed closely by the graphite and iron.

Fire-clay Crucibles. — The most satisfactory clays for crucibles are those which burn dense at comparatively low temperatures and at the same time, when mixed with burned clay or grog, do not glaze at higher temperatures. Clays which become stiff and glassy at high temperatures do not suffer sudden changes of temperature without cracking.

Analyses of suitable clays are as follows:

Silica, 44 to 66 per cent } Total silica and alumina, generally
Alumina, 25 to 35 per cent } 80–88 per cent.
Ferric oxide, 1.5 to 3 per cent.
Lime and magnesia, up to 1 per cent.
Loss on ignition, 9 to 18 per cent.
K_2O, 1 to 2 per cent.

In order to obtain the desirable mechanical, physical and chemical properties the clay is mixed with suitable additions of grog or burned clay of suitable grain to make a homogeneous and strong crucible.

English crucibles for melting gold and silver are made of two parts best Stourbridge clay and three parts grog of three-millimeter grain. In Germany the general rule is one part of clay to two of grog, in France about the same. Beaufay crucibles contain 64.6 per cent silica, 34.4 per cent alumina and 1.0 per cent ferrous oxide.

Freiberg crucibles and scorifiers are made of a mixture of burned and unburned Oberschöna clay, free from quartz.

The material is moulded by hand or with the help of cores or forms of the shape desired. They are dried slowly in chambers or on a hot floor for several weeks at a temperature of about 30° C. and then burned.

Quartz-bearing Clay Crucibles. — An addition of quartz, homogeneously worked into the clay so that in the heat it forms a stiff skeleton, makes the resulting crucible resistant to alternate heat and cold. It lessens its power of resistance to chemical agents and fluxes with metal oxides and alkalis.

Hessian crucibles are made of equal parts of Grossalmeroder clay and sand of regular even grain.* Quartz vessels are now prepared from pure quartzite and find favor in chemical laboratories.

Carbonaceous Crucibles. — To this class belong all crucibles which contain carbon in some one form or other, such as coke, graphite and charcoal. These crucibles fill a special rôle in the steel and other industries and are almost indispensable. The carbon of the crucible is infusible, and because it prevents the influence of oxides, the crucible is long lived. It also assimilates the mixture of clay with which it is generally worked to make a suitable mass for the moulding of crucibles. Of all the forms of carbon used, graphite is the most satisfactory since it is the densest and most inflammable. All the forms of carbon are good heat conductors, so that a graphite or carbon crucible is a good heat distributor. A beautiful, smooth and even surface may also be assured in a graphite crucible, so that the pouring of a charge is simplified and the opportunity for corrosion by the charge decreased.

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* See chapter "Refractories used in the Chemical and Electro-metallurgical Industries," page 184.

In making crucibles from a mixture of clay and graphite, such as the valuable ware of the Joseph Dixon Company and of Messrs. Morgan of Battersea, the utmost care must be exercised in selecting graphite of suitable character. It should be of such density as to be relatively inflammable, must have a low percentage of ash and possess a long cleavage and leafy structure. Ceylon and some American graphites like Ticonderoga are most satisfactory. The clay used for admixture with the graphite need not be of extraordinary degree of refractoriness since the graphite protects the clay. In burning the crucible it should be painted with a solution of water glass or soda solution. Sometimes 3 to 5 per cent of feldspar is added to the crucible mass. This vitrifies and absorbs the dust in the fire gas during the burning. If the clay used is fused at a fairly low temperature, no addition of protective covering or slag will be necessary. Grog and quartz sand are often added to the mixture. The former prevents premature cracking and the latter lessens the shrinkage during the process of burning.

The Manufacture of Graphite Crucibles. — The mass of mixture used depends on the quality of the fire clay and graphite and on the purpose for which the crucible is intended. On an average one to three parts clay are mixed with one part of graphite. Sometimes the mixture used consists of fire clay (about 75 parts), quartz (about 25 parts) or chamotte (somewhat less than 25 parts) to every 100 parts graphite. For the highest class crucibles larger proportions of graphite are used.

The quartz should be free from dust and from iron in all combinations. It should be in the form of clear grains about pinhead size. The crucibles of the English Plumbago Company were made of equal parts Stourbridge clay and Ceylon graphite and contained 52.6 per cent carbon. Hessian graphite crucibles are made of graphite, kaolin and Hessian fire clay in which the graphite is about 50 per cent of the mass. The crucibles made for the antimony industry in England are composed of 44 parts graphite to 200 parts clay.

Some French crucibles are made as follows: six parts of Gironde clay and seven parts of grog made of the same clay and crushed and screened. The reject of a 20 mesh is mixed with four parts graphite, one part crucible grog and one coke. The whole is ground, mixed, kneaded, and moulded into forms, dried and burned. The following analyses * of crucibles represent present practice.

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* *Handbuch der gesammten Thonwaarenindustrie*, von Bruno Kerl, p. 954.

	1	2	3	4	5	6	7	8
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
SiO_2......	25.91	27.22	33.44	34.03	32.67	37.09	31.40	31.31
Al_2O_3.....	11.26	7.03	15.70	12.95	11.52	14.58	19.57	17.30
Fe_2O_3.....	0.48	0.51			2.79		1.78	
CaO, MgO	Trace	Trace	.....	.....	.....	.....	0.30 CaO 0.80 MgO	.....
Graphite .	58.24	62.54	48.15	50.18	48.68	44.40	42.08	47.40
Water	2.77	2.42	0.77	1.63	1.50	2.92	1.20	3.42
	98.66	99.72	98.06	98.79	97.16	98.99	97.13	99.43

1 and 2. Hesse.
3. Rhenish.
4. Duesseldorf.
5. Sample of a German crucible used 18 times.
6. London (Morgan).
7. English.
8. American.

Coke and Charcoal Crucibles. — These are in reality crucibles of clay to which has been added a small quantity, not more than 10 per cent, of coke or charcoal. Larger quantities make the crucibles porous and increase the degree of contraction. The carbon in this form is more combustible and more easily absorbed by the steel or other charge in the crucible. Some English mixtures are:

(*a*) Nine parts Stourbridge clay, 1 part coke fines, 2 parts crucible grog.

(*b*) One hundred parts Stourbridge clay, 100 parts Stannington clay, 10 parts crucible grog, 1 part coke fines.

A German mixture: 30 to 35 parts raw fire clay, 45 to 50 parts burned fire clay, and 15 to 20 parts coke.

So-called charcoal crucibles are sometimes used in the steel industry. These are composed of a mixture of about 9 parts fire clay, 14 parts grog and 6 parts charcoal. By the addition of sawdust or charcoal dust the crucibles may be made porous. Crucibles of carbonized wood, made by turning the shape from suitable wood and carbonizing, and coke crucibles, composed of fine coke bonded with pitch and burned under cover so as to exclude air, have been used without giving great satisfaction.

Preparation of Crucibles. — The clay is dried, cleaned, crushed and sieved. The grog is made by burning the raw fire clay or is prepared from broken crucibles. The graphite is milled in small edge runners which break the mass up into scales. The constituents of the mass are then carefully weighed so as to correspond to the calculated charge and then thoroughly digested with water in a small pan mill until the mass has the consistency of dough.

The paste is then rolled into balls or blocks and stored under wet cloths in cellars until the mass is homogeneously saturated with moisture. The crucibles are moulded by tamping the mass into wooden or metal moulds, by moulding over a core or by throwing on a potter's wheel. For further descriptions of the details of the work of moulding crucibles the reader is referred to Kerl.*

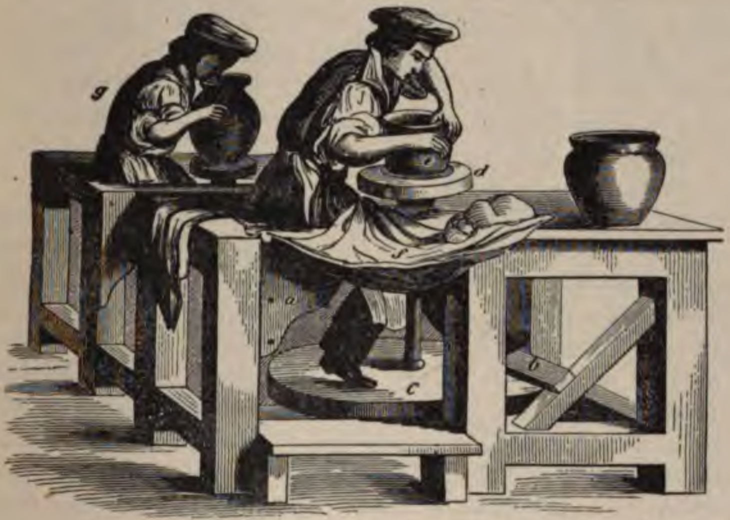

FIG. 86. — Throwing Clay Vessels on the Potter's Wheel.

Drying Crucibles. — Crucibles are dried slowly and the temperature is gradually increased until the crucible is completely dry. Too speedy drying causes large loss through cracking. Drying chambers may be heated by steam pipes or they may be built above and about the burning kiln. Sometimes two drying chambers are used; in the first the drying may be effected in a closed room with steam at a temperature of about 30° C. while the second drying may be done at a temperature of about 50° C. in a chamber through which the hot gases from the kiln may pass.

Burning Crucibles. — It is seldom that the crucibles made for home consumption by steel and other manufacturers are specially burned. After being thoroughly dried they are subjected to a long preliminary heating before being charged. In the case of smelting charges in crucibles placed in reverberatory furnaces the dry crucibles may be charged and set in the coolest end of the furnace and gradually moved down toward the pot or fire-box end.

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* *Handbuch der gesammten Thonwaarenindustrie*, pp. 956, 957, and 958.

If the crucibles are specially burned this operation should be done at a relatively low temperature. Fire-clay crucibles are burned at Seger cones 7 to 12 (1310 to 1370° C.); graphite crucibles between cone 018 and 010 (710 to 950° C.). It is necessary in burning the graphite crucibles that they be protected from burning by placing them in capsules or muffles. If the graphite should be burned to a small extent on the surface which will be indicated by a brownish color it is usual to prepare the crucibles for the market or smelting house by rubbing fresh graphite over the surface.

Protective Coverings for Crucibles. — These are often used in order to protect the crucibles from the chemical attacks of the charge, to prevent the absorption of moisture by the crucible and also to increase the refractoriness at high temperatures. These protective coverings may be composed of mixtures of clay and graphite. A mixture of one part of fire clay and three parts of graphite painted to a thickness of half an inch is said to increase the life of the crucibles used in the smelting of manganese ores. Sometimes the crucible is dipped in tar which is carbonized at a moderate temperature in the reducing flame. Crucibles are protected from damage in transport and from the absorption of moisture by painting with a varnish of resin, gum or pitch dissolved in turpentine or alcohol. Sometimes the crucibles are glazed by dipping in a solution of chloride of lime and by painting on a paste consisting of 8 parts of powdered quartz, 15 parts of clay and 5 parts of lime. A coating of two parts of magnesia, 2 parts of fire clay and 1 part of quartz burned into the crucible protects the charge against the reducing influence of graphite. Efforts have been made to increase the refractoriness by painting crucibles with some of the carbides, such as carborundum, and melting them on the crucible with the heat of the electric arc. Paints of amorphous carborundum may be made by mixing it with water glass or boric acid. After painting this on the crucible the latter is burned. There is no doubt that for certain purposes these protective paints increase the life of the crucibles. Sometimes the crucibles are coated with highly refractory oxides such as alumina. This is done by dipping the crucible into melted cryolite. The refractory oxides with a high melting point may be fused by means of the electric furnace.

Special Crucibles. — For purposes in which the molten charge may not be brought into contact with silica or carbon, crucibles may be used which are made of lime, magnesia or alumina. Lime crucibles of small dimensions are made from pieces of burned lime; in order to preserve them from damp air these may be kept in paraffin. The smaller crucibles are made on the turntable. The larger sizes are produced by tamping, first of all, a fire-clay crucible full of black lead or soot and then scraping out the core to the size of the required crucible; in this hollow burned lime is stamped and in this, again, a space is hollowed out which will have the interior dimensions of the crucible required. By another method the lime may be moulded around a core and this shape placed inside the original double-walled crucible of fire clay and lampblack.

De Bois makes crucibles from a mixture of silica and heavy spar by milling, washing, filtering and pressing the mixture and moulding the shapes and burning them. Magnesia and less often chrome crucibles are formed about a mould in an electric furnace.

Magnesia Crucibles. — Mr. George Weintraub,* of the General Electric Company, of Schenectady, N. Y., makes refractory articles of magnesia, alumina, thoria, etc., without the use of a binder. The magnesium oxide is first heated in an electric furnace to a high temperature in order to let it assume a stable condition. This firing causes the magnesia to cake together so that regrinding is necessary. It is ground to the fineness of flour in a tube mill. A mould is then made for the article to be produced, say, a crucible. This mould is made of carbon or graphite and a layer of the powdered magnesia is placed on the bottom. A carbon or graphite plug is now placed centrally in the crucible upon this magnesia layer. It is surrounded by a layer of paper which permits the magnesia to shrink when heated. When moulding a crucible of $2\frac{1}{2}$ inches inside diameter, a paper of from $\frac{1}{16}$ to $\frac{1}{8}$ inch thickness

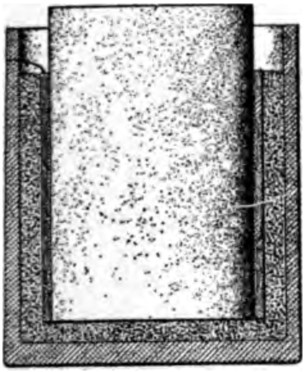

FIG. 87. — Preparation of Magnesia Crucibles.

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* *Metallurgical and Chemical Engineering*, Vol. 10, p. 308.

is suitable. The space between the walls of the mould and the paper-covered core is then filled with magnesia powder and packed to a certain degree by shaking and bumping. The mould is now placed in an electric furnace and heated to about 1500° C. When finished and the mould is cooled, the walls of the magnesia crucible contract upon the layer of loose paper carbon, so that cracking is avoided. The finished crucibles are smooth, homogeneous and strong and may be safely handled and may even be worked on the lathe. Tubes may be made in the same way.[*]

Another method of doing this is shown in the accompanying figure;[†] *b–b* represent the carbons and *a* is a carbon tube which acts as resistant. The hollow charcoal tube is filled with powdered magnesia and on applying the current, fuses and runs down over *C* which shapes it into the required form and dimensions. Other crucibles of this order are the plastic asbestine or magnesia silicate ware. Serpentine, chlorite and talc may also be used.

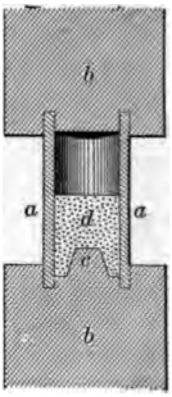

FIG. 88. — Preparation of Electrically Fused Magnesia Crucibles.

Asbestos Crucibles. — Asbestos has the property of holding crucibles together and often saves a charge when the crucible cracks. It is used in admixture with fire clay, magnesia and other materials. One mixture consists of: burned fire clay, 10 parts; graphite, 10 parts; asbestos, 15 parts (the threads may be not more than one-eighth inch long); quartz, 3 parts, and fire clay, 22 parts. Another mixture consists of 3 parts fire clay, 2½ parts graphite, 2 parts powdered asbestos, ¼ part magnesia, ½ part quartz. The whole is mixed with water glass and moulded. The asbestos itself is not particularly refractory and at high temperatures deteriorates and crumbles. Alumina crucibles are made by mixing together alumina and fire clay. Crucibles are made from molten alumina by placing a suitable core in the pure molten alumina and allowing it to solidify slowly. The alumina is in the form of cryolite or other pure mineral and is melted by the heat of the electric resistance or arc furnace.

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[*] U. S. Patent, 1,022,011, April 2, 1912.

[†] Kerl, *Handbuch der gesammten Thonwaarenindustrie*, p. 963.

Zinc-distilling Vessels. — These serve in distilling zinc from its ores and must be able to resist the action of not only molten zinc and impurities like lead but the fume and gas from these metals.

An extreme refractoriness against high temperature is not so much desired as a material resistant to the chemical influence developed in heating these zinc ores and materials. The distilling retorts and vessels in the zinc industry are made largely at the smeltery, since special care is required and the successful operation of the plant depends on the character and life of the retorts. The life depends greatly on the degree of density produced in the clay mass in burning. The lean burned clay (chamotte or grog) should not shrink on heating. It is to be mixed with just sufficient plastic clay and water which permits the moulding of the retorts and shapes and adds sufficient mechanical strength to the mixture so that it may not crack prematurely. This latter quality of strength is also imparted in part by working and kneading and by stamping the mass previous to moulding it. Two distinct kinds of vessels are used in zinc distillation, the retorts, or cylinders, and the muffles. The use of the retorts, or cylinders, is general in Belgium, England and America; both muffles and retorts are used in Germany. Silesian practice favors the use of muffles, the Rhenish works prefer, as a rule, retorts.

Retorts. — The Belgian retorts are circular in cross section, and the Rhenish are elliptical. The former are used in the majority of American works, although at least one large plant has installed the Rhenish. One Belgian furnace consists of about 80 retorts arranged in four or five rows one above the other and all slightly inclined upwards away from the front of the furnace. In America, a single block or double furnace, that is, a furnace with two working sides towards which retorts are inclined, holds from 200 to 800 retorts. The muffles are the largest, the elliptical sectioned retorts being somewhat larger in cross section than the cylindrical ones.* The elliptical retorts are stronger, and may, therefore, be made longer than the cylinders and at the same time may be made of larger cross-sectional area. The walls do not need to be so thick, as in the cylinders, since the retort is better braced by its shape and stronger. The retorts do not exceed 6 feet in length in the case of the muffle, or 5 feet in that of the Belgian and Rhenish shapes. The cross-sectional area of the muffles does not exceed 27 inches by 6 inches; of the retorts 13 inches by 8 inches; cylinders 8 inches in diameter. Cylindrical retorts, with walls one inch thick and butts 2 inches, measuring from 46 to 58 inches in length, with a diameter of 7 inches, have an inside volume of from 1693 to 2155 cubic inches and weigh from 86 to 107 pounds. To find the weight of clay required to make these it is only necessary to calculate the proportion of grog used in the batch and the percentage of water in the raw clay, which burns dry. Muffles weigh from 450 to 600 pounds. These take a charge of about 250 pounds of ore and fuel; cylinders hold from 50 to 90 pounds. They must carry these weights comfortably at high temperatures. Yet the walls may not be made too thick or the transmission of heat to the charge will be delayed and the reduction distillation made tedious and costly.

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* Ingalls "Metallurgy of Zinc and Cadmium," p. 217.

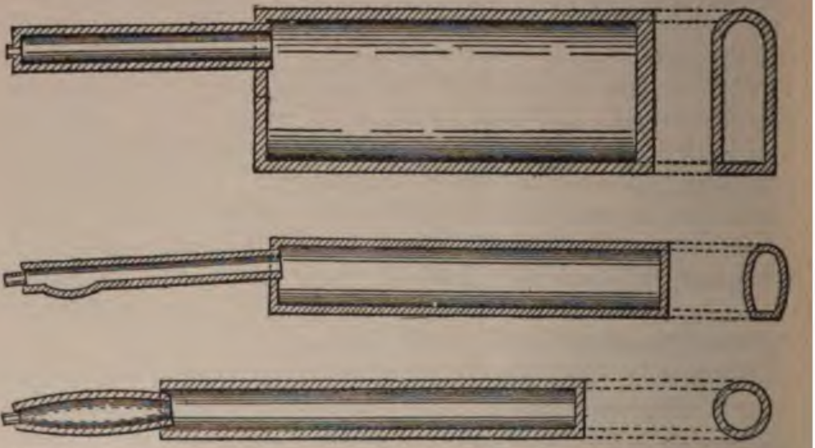

FIG. 89.—Sections of Silesian, Rhenish and Belgian Retorts with Condensers.

W. R. Ingalls states clearly the requirements of the batch in the manufacture of crucibles and I quote freely from his book, "The Metallurgy of Zinc and Cadmium." As in most departments o ceramics the zinc smelter does not bother to make tedious experi— ments with refractory materials with a view to obtaining the bes possible mixture or batch, but having obtained a clay which bond with chamotte, is reasonably refractory and burns dense an strong, he is disinclined to continue further investigations. A the same time his choice is made difficult by the fact that the most refractory clays do not make the best bonds with chamotte and do shrink considerably in burning, while the dense-burning clays, which shrink little, are less durable. The smelter's chief aim, then, is to make a judicious mixture of the two. Although the chemical composition of the retort batch varies it is always composed of raw fire clay and crushed chamotte. The chamotte consists invariably of fragments of disused or faulty retorts which are selected so as to eliminate the pieces which are saturated with metal. These are ground to rough, angular splinter grain. To make special high-grade refractory retorts it is advisable to use fresh chamotte, that is, burnt virgin clay. The percentage of zinc in the broken retorts varies from six to ten per cent. The larger content makes the use of the old retort material prohibitive.

Although we may accept the axiom that the batch should be low in fluxing bases, such as the oxides of iron and the alkalis, yet it is well to prepare the mixture with a view of meeting and resisting the efforts of the gangue of the ore to make a neutral slag. With, for instance, an ore carrying high silica it is well to make the batch more silicious by the addition of such material as quartz or an arenaceous or silicious clay. The American metallurgist is more fortunate in his choice of clay materials than his European brother. The deposits of New Jersey and Missouri offer a wide choice of excellent clays. Ingalls* reports many analyses of retort material both in Europe and America. Suffice it to say that the satisfactory retorts show content of silica varying from 44 to 70 per cent and of alumina from 20 to 45 per cent. The content of metal and alkaline oxides must not be much above 2 per cent. It serves little purpose to give the many analyses of different retort batches in this place, since the chemical composition alone is insufficient guide in the choice of a clay. The various refractory companies, the steel and the general metallurgical industry are in a more favorable position now, in knowing the qualities and particular fields of use of the good American clays. Too much praise cannot be given to the various State Geological Surveys for their efforts in making the public conversant with the results of their examinations of the clay deposits of North America.

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* "Metallurgy of Zinc and Cadmium," pp. 225–228.

PREPARATION OF THE CHARGE OR BATCH FOR RETORTS AND MUFFLES

Grinding. — The clay and chamotte are first ground in pan mills in which two rolls "chase" one another on a pan on to which the batch is fed, or between vertical rolls such as are used in coal and ore crushing. Other mills used are of the coffee-mill type. The roller-chasing type of dry pan is most used.

The clay should not be ground to impalpable powder; usually a 2-mm. grain is used. The chamotte should be coarse (about 5 mm.) and the grain rough and angular so that it will bond well with the plastic clay.

For larger ware the chamotte may be coarser but it tends under these conditions to make the vessel porous, pervious to gases and physically weak. An admixture of some chamotte is indispensable. Depending on the coefficient of shrinkage of the clay used and its capacity to burn dense, varying proportions of chamotte are used. Generally 3 parts of chamotte are mixed with two parts of raw clay; the chamotte consists, in general, of part old material and part newly burned clay. The latter may be replaced in some part by lean materials, such as coke dust, which lends smoothness and finish to the burned product and counteracts the tendency to crack. Sand is sometimes used instead of coke dust but in smaller quantities.

When milled and ground the mass is mixed and kneaded with water. This may be done by shoveling on a floor and mixing in the water, rolling the mass into balls and tempering these in a cool room under wet sacking so as to distribute the moisture homogeneously throughout. This procedure may be carried out in a horizontal pug and kneading mill. This consists of a horizontal shaft fitted with blades and completely confined in a casing. The mass is fed in at one end and worked by the revolving knives to the other. These machines are about eight feet long.

In Germany the retorts are formed by hand in a mould with or without a core but are generally pressed by an auger machine in America. These auger machines are either horizontal or vertical.

The clay is dumped into the cylinder, which is provided with a vertical or horizontal shaft fitted with blades set at a suitable angle, which press the clay downward or forward, and force it around a core, the dimensions of which represent the clear measure of the retort, and through a die plate into a receiving form. When a clay cylinder or retort of the required length has been made, it is cut by a wire hanging beside or above it. A butt is added to the retort sometimes by tamping in a section above the retort about 8 inches in diameter and 2½ inches thick. The receiving form is made in sections. The retort is kept in this form during the first two or three days of drying. The receiving form is made of three wooden segments, generally in two parts, a longer upper and a lower section. The wood segments do not close tightly about the retort but allow the insertion of staves. The whole is held by iron rings and clamps, as is seen in the illustration* (Fig. 90), so that the form may be easily removed when the retort is firm. The retorts dry ten to twelve days in the air and about fifty days in the hot room. Hydraulic presses are at times used instead of the pug and auger mill in moulding the retorts.

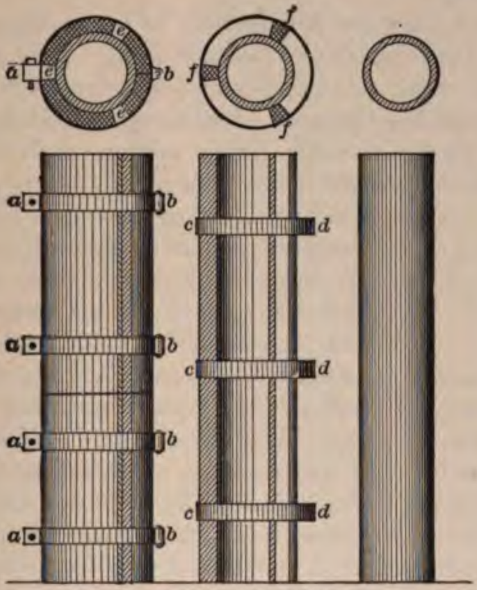

Fig. 90. — Preparation of Zinc Retorts.

In at least one plant in Belgium the column of solid clay, which is formed by working the batch in a long canvas sack, is reamed out to make the retort.

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* Ingalls, "Metallurgy of Zinc and Cadmium," p. 236.

Attached to the retorts, when in use in the zinc furnace, are condensers of fire clay in which the fume condenses to metal. These are made from a batch of less refractory quality, but of similar components to those used in making retorts. These condensers are handled considerably and last only ten or twelve days. They must therefore be inexpensive.* In America the simple conical condenser is used and measures from 24 to 18 inches long by 5½ to 2½ inches in diameter, with walls 2 inches thick. They are moulded by hand about a mould of the external shape and formed by a core of the internal shape.

In Germany they are moulded by folding a sheet of clay of the required thickness about a wooden form. They are dried for many weeks. Both retorts and condensers are burned carefully in kilns or annealing furnaces. Sometimes the retorts are glazed by painting with a lead-free fusible mixture of salts and clays. One such mixture consists of 60 parts clay, 30 parts glass and 10 parts soda. Common salt, water glass and soda have all been used. Glazing is not common in America since the retorts often form a kind of glaze or protective coat from their own constituents. Dried ware is burned in kilns of the downdraft type. The retorts are placed vertically on the floor of the kiln which has been covered with ground chamotte. The retorts are tempered from 12 to 15 hours at a temperature which reaches a maximum of 900° C. In the zinc districts of America these are often heated by natural gas, sometimes by waste heat from the zinc-distilling furnaces, and often by coal from a Parsons' or ordinary fire box. The connection of the condenser to the retort is made by luting the former into the retort with plastic clay. A supply of this is always kept on hand to plug up any leaks of the fire gases and any cracks in the furnace wall. Defects and cracks in the retort should be repaired with good fire clay or plastic fire clay and chamotte. The construction of a typical American-Belgian zinc-distillation furnace is shown in Fig. 91.† The ore mixed with the reducing agent is placed in the retort, which is subjected to the heat of the five gases, and the metal resulting from distillation is obtained in the attached condensers. Fig. 67 shows a Faber du Faur furnace, used for expelling zinc from the zinc-silver-lead crust obtained in desilverizing molten base bullion by the addition of zinc.‡

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* Ingalls, "Metallurgy of Zinc and Cadmium," p. 243.

† Ibid., p. 436.

‡ Parkes' Process.

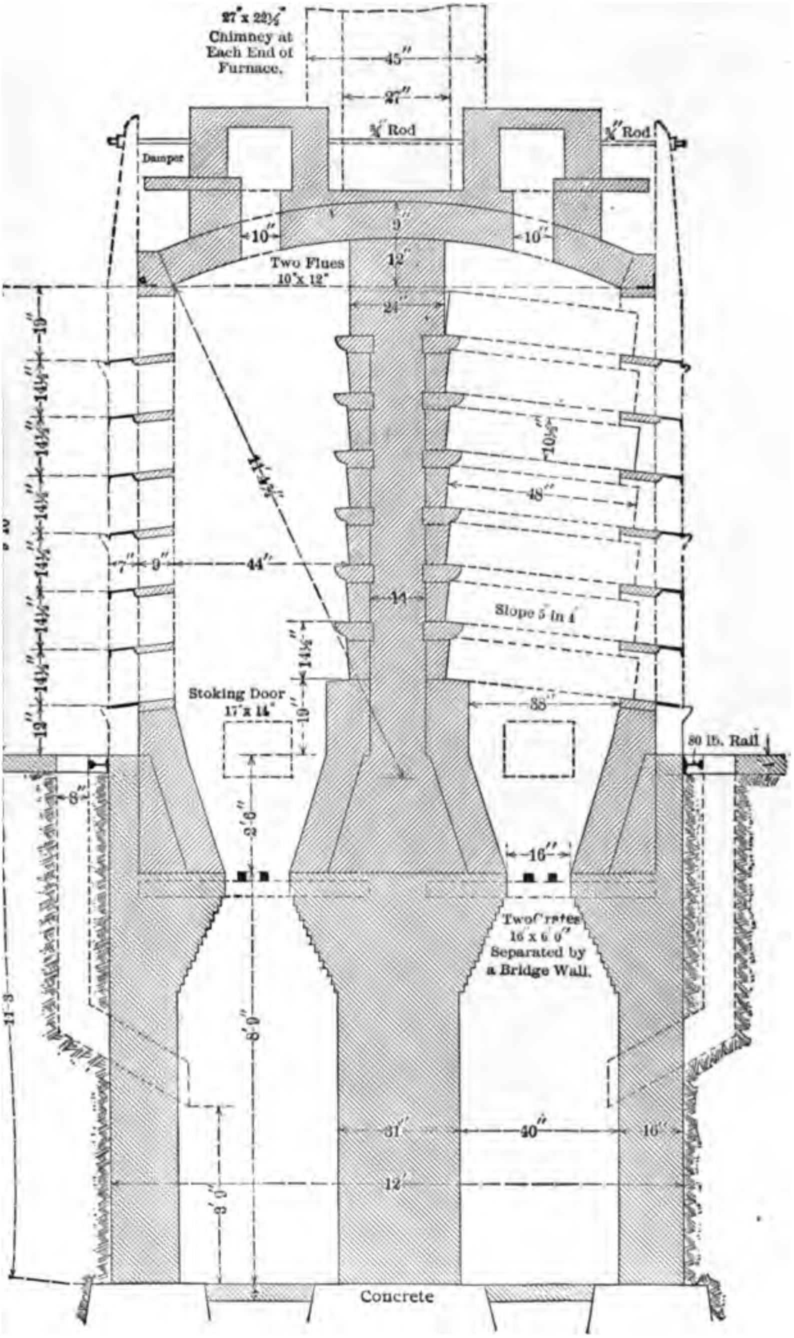

Fig. 91. — American-Belgian Zinc-distillation Furnace.

Gas Retorts. — Under this name is understood the vessels in which city gas is obtained by the heating of coal without admission of air. The chief physical claims made on the vessels are

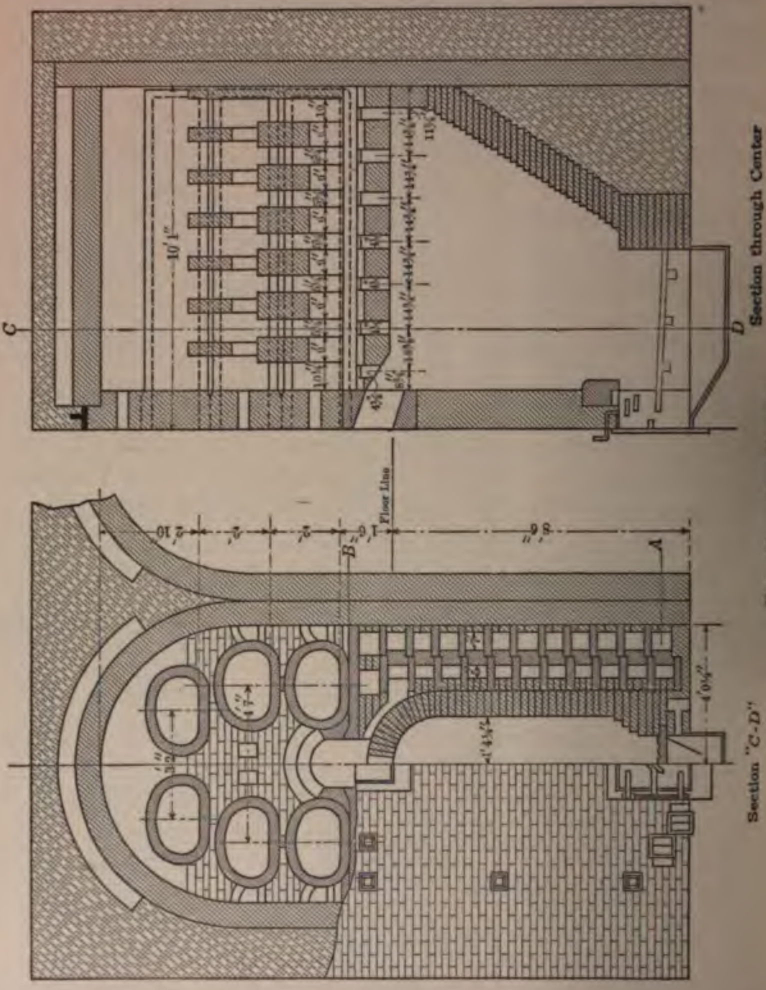

Fig. 92. — Gas Retorts.

that they should withstand sudden changes in temperature. The material need not be especially infusible or even dense.

The graphite, deposited during the decomposition of the coal, effectively coats and protects the retort. The retorts themselves are either semicylindrical or elliptical in cross section. In Germany they are made from 17 to 21 inches wide, and are from 12 to 16 inches high, inside measure, and 7 feet 6 inches to 10 feet long. These retorts are perhaps the heaviest pieces produced in the refractories industry; their weight varies from 1000 to 2750 pounds. They are made from 2½ to 3 inches thick, and in the case of the cylindrical retorts with a mouthpiece, this latter will be from 4 to 5 inches thick. The iron door is fastened to this mouthpiece; it is required to bear considerable wear and tear.

The German Institute of Gas Engineers has determined a scale for the dimensions and weight of both elliptical and muffle or semicylindrical-shaped retorts.*

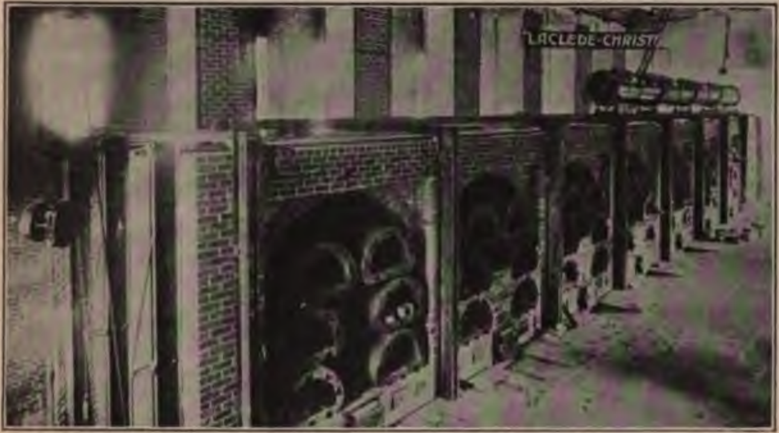

FIG. 93. — Gas Retort.

The mass used may be either fire clay (1) or silica (2). In Germany the fire-clay ware is preferred. The batch consists of clay and chamotte (this is the German name for grog) and is finding acceptance more and more generally in the United States. As a rule one part of plastic clay is mixed with from one to one and one-half parts of chamotte. The plastic clay may be made of a mixture of different clays, sometimes with the addition of highly refractory kaolin and clay schist. The chamotte is made by burning clay or it may be composed simply of broken refractory clay products like retorts, crucibles and capsules. It is of great importance that the surface and the form of the chamotte grains should be sharp and rough so as to effect a good bond with plastic clay. The size of these grains should be above one millimeter. Anything which passes through a 1-mm. sieve must be discarded. As a rule the grain varies from 1 to 6 mm. in diameter.

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* This is published in Kerl, *Handbuch der Thonwaarenindustrie*, p. 988.

Kerl gives several formulas for making the batch: (1) Four parts of sifted clay from Halle, 2 parts of sifted plastic Westerwald clay, 8 parts of chamotte about the grain of peas and 2 parts of chamotte of pinhead grain.

At one of the Rhenish works the batch consists of: (2) Forty-six parts of chamotte hard-burned grain, from 1 to 5 mm. in diameter, 22 parts of plastic Westerwald clay, 27 parts of Ebernhahn clay and 5 parts of china clay.

FIG. 94. — Gas Retort Plant.

The clay is generally ground fine and well digested with the required quantity of chamotte. This may be done on a horizontal shaft and knife pug mill or in a pan mill. The stream of batch coming from the mill is cut into balls and dried in order to free the mass of some of the water added to the batch. When the balls have such plasticity that they may be moulded by hand without ejecting water they are covered with wet cloths and stored until their moisture is evenly distributed throughout the mass.

The moulding of the retorts is done almost exclusively by hand in open wooden forms with and without the use of a core. The clear dimensions of the mould correspond to the outside dimensions of the retort. The mould is made up of from 6 to 8 parts which may be screwed together. To make a complete retort a number of the moulds are placed one on top of another. In making the retort without the use of a core the bottom is first tamped upon a wooden foundation plate and then the periphery is made by pressing the batch against the sides of the mould placing one mould above another as each section of the total length is finished.

If a mould is used it should be made of 5 parts, consisting of a central piece of rectangular section surrounded by four pieces having a cross section of the shape of a segment of a circle. The five core pieces make a solid cylinder, the dimensions of which correspond to the inside measurements of the retort. The whole core is necessarily long and heavy; each piece, therefore, is provided with an eyelet or a ring so that it may be lifted out by means of chain blocks. First of all the bottom is tamped upon the wooden foundation plate with a special cast-iron tamping iron which has a square head with a surface cut into teeth. After the bottom is firmly tamped it is pressed and smoothed with a wooden tamper having an even, smooth surface. The core is now placed in position and firmly wedged so that the distance between the mould and the core is the same throughout. Now 6-inch sections

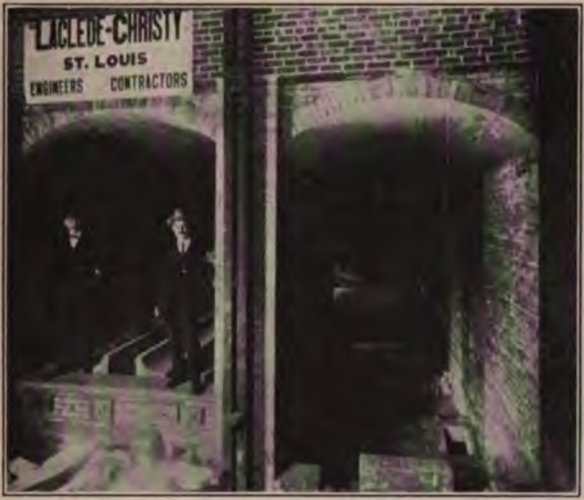

Fig. 95. — Method of Holding Retorts.

are tamped in and after the completion of each section this is firmly pressed down and tamped by the tamping iron with the rough surface.

As soon as the mass has reached almost to the top of the mould another section is placed upon it and the work continued until the whole length has been tamped in. The uppermost section is in some cases wider than the rest and forms the mouthpiece of the retort. In such cases a larger mould corresponding in shape is used. The core is now removed carefully and the whole retort along with the mould laid horizontal when it is smoothed and cleaned, in some cases by means of the hands of a workman who crawls through it. The mould is then removed and the outside of the retort cleaned and smoothed.

Drying. — The retorts are dried in a drying chamber with which special care is taken to promote the reasonably quick drying of the inside which may be done by blowing hot air through the retort by means of a fan.

Glazing. — Sometimes the retorts are glazed when dry in order to make them impervious to the passage of gas. Lead glazes may not be used; more often porcelain and salt glazes are used. The porcelain glaze consists of 84 parts ground feldspar, 35 parts calcium carbonate, 26 to 91 parts china clay and 54 to 204 parts quartz sand. It is not necessary that the glaze be quite white. The glaze is made into a mixture with gum arabic, dextrine or some other paste and painted on the inside of the retort to a thickness of about one-eighth of an inch.

Burning. — The glazed or in-glazed retorts are burnt in downdraft kilns of various types such as the Casseler furnaces and in the Mendheim and Schmatolla furnaces.

The Kulmiz furnace,* which is fired by gas or half gas, is especially suited to the burning of retorts. These are placed vertically on a bed of ground chamotte or sand. The furnace is very slowly heated and cooled. The retorts must be homogeneously heated to a high temperature and the flames should not lick any part of them.

When the retorts are taken out of the furnace they are carefully examined, the small cracks are brushed with mud, the large cracks filled with mortar consisting of graphite, clay and borax or, as practiced in one factory, with a mixture of 5 parts ground chamotte,

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* Described in Kerl, *Handbuch der Thonwaarenindustrie*, pp. 877 and 878.

5 parts powdered glass, 1 part powdered borax. A mixture that has been found very serviceable in repairing retorts already in use consists of a powdered heavy spar and water glass.

A number of gas plants in England, Germany and America use the inclined retort in which the ends incline toward the central axis, thus contracting about 3 inches. In burning, a special head piece is moulded on to the retort so that it may stand vertically in the burning kiln. This piece is removed after the burning is complete.

The horizontal retort is being replaced to some extent by inclined retorts and by vertical ovens. In this case no retorts are used, the furnace having a structure similar to a by-product coke oven. The American retorts are placed 6, 8 or 9 in a block. The English and American retorts are about 10 feet long. Of a number of gas works reporting to the English Refractories Committee * twenty-three used retorts 22 inches by 16 inches in clear cross section, twelve used retorts 21 inches by 15 inches and six used inclined retorts 24 inches to 21 inches by 16 inches. These reports represented 1748 horizontal, 310 inclined and 1 vertical retort. In thirty-three works the retorts were moulded and in twelve were built in segments. The average life was 797 days without patching and 1257 with patching and repairing. The life of the combustion chamber was 1321 days.

The temperatures in the retorts ranged from 1558 to 1909°, in the combustion chamber from 2212 to 2397° and in the regenerators from 1220 to 1622° F. The life of the checker-work is on an average 415 days.

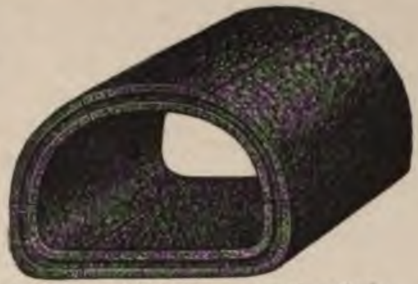

FIG. 96. — Silica Retort for Gas Plants. (Known as the Ricon Retort.)

A new departure in methods for prolonging the life of retorts is the procedure of Sewatsch † who makes the head or mouthpiece and the bottom separate from the retort itself and allows a free space between the heat and the retort which is filled with asbestos or asbestos and fire clay. As the retort is heated it expands and pushes the asbestos up to the mouthpiece.

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* *Journal American Gas Institute*, July 11, 1910.

† *American Gas Light Journal*, Vol. 2, 1906.

A very satisfactory retort in America is made of silica, in small sections, and placed together in the block or furnace. These expand with the air and become tight fitting. The silica is impervious to gas and extremely resistant to heat and change in temperature.

Hydraulic presses produce a dense and thoroughly homogeneous retort. It is easy to make the irregular elliptical shapes in such a press and at the same time provide an even thickness of material. Sometimes two sets of presses are used. In the first the cylindrical shape is made; in the second this is moulded into the required elliptical or other shapes.

CHAPTER XIII

TESTING OF REFRACTORY PRODUCTS AND REFRACTORY RAW MATERIALS

The quickest way of determining the refractory qualities of brick and finished material lies in subjecting a fair sample to heat, or heat and pressure, and observing the temperature at which it softens, or the contraction or elongation at the temperature to which the refractory must be subjected.

This determination may be carried out in a reverberatory furnace, with a hearth area of about 4 square feet, fired with coal, oil or gas. If bricks are being tested they are made into a column 2 feet high and 9 feet square. This column may extend out of the roof of the furnace. On the top of the column pig-iron bars are placed which amount to from 50 to 75 pounds to the square inch of surface.

The contraction or expansion is measured carefully. From these measurements a comparative scale may be obtained showing the divergence of the bricks under test from the standard requirements. Hollow ware may be tested in a similar manner. With this simple test is often coupled the test of porosity. This is done by heating the brick and vessel to about 90° C. and then placing in water so that the upper surface of the brick or vessel is at the level of the water, thus allowing the air to escape. The difference in weight before and after immersion lends sufficient data to calculate the porosity, as described later in this chapter. But for comparative purposes the weight of the water absorbed is sufficient, at least, to determine the class of refractory materials in which it may, on account of its porosity alone, be placed. Coefficients are often given, accordingly, indicating the percentage of water absorbed.

Sampling. — In selecting a sample of pieces of ware for chemical or physical examination, it is important that it should be taken from a whole section of the brick, and not from corners or fragments, since these are liable to contain impurities arising from the ash or gases of the fire boxes.

The most important preliminary tests of raw materials for all refractories, except fire clay, are the chemical and rational analyses. Silica or ganister should be crystalline, dense, hard and gray, or white, with little discoloration from iron and but small indications of lime, talc or clay either on the cleavage of the stone or in the form of veins traversing the mass. Rock in ledges must be especially carefully examined. Boulders are generally freed by weathering, from all unsatisfactory admixed minerals except iron oxides, which are more permanent. Under the microscope the ground ganister should show semitranslucent splinters heterogeneous in size and shape.

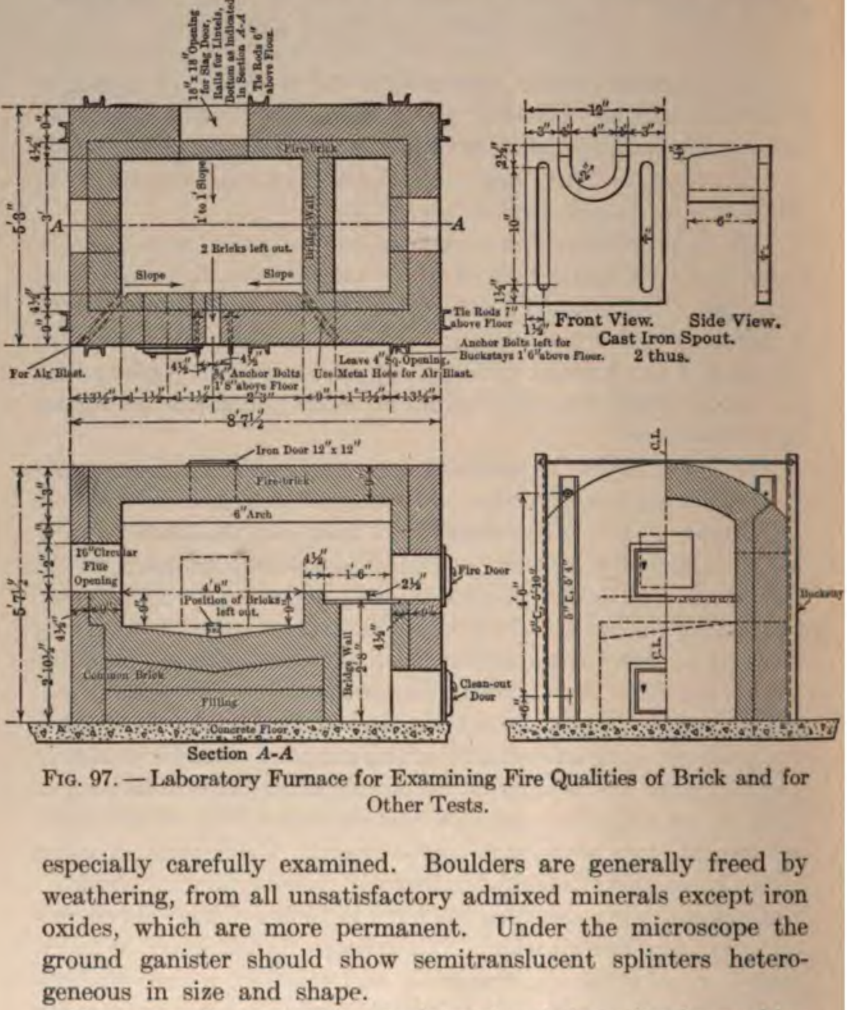


Fig. 97. — Laboratory Furnace for Examining Fire Qualities of Brick and for Other Tests.

Clays must be treated first to determine their purity, by washing and screening the sand and dust contained in them. The next important determination is that of the amount of water required to make the clay plastic or mouldable. The condition of the clay after becoming plastic and its adhesiveness or stickiness will indicate the degree of workability. To determine the refractory qualities the clay is cut into bars about 8 inches by ½ or ¾ inch square. These are dried, and the measure of shrinkage noted. The bars are then burned under gradually increasing temperature which is checked by the ample use of cones. The furnace is first heated and then cones, from 0.7 up to the highest number at the softening temperature of which the clay is to be tested, are inserted. The degree of shrinkage is noted as each cone turns down until the contraction becomes uniform or ceases. A curve may now be plotted. This will indicate the temperature at which the clay should be burned to produce a sufficiently strong and durable product. This temperature is represented by the lowest point at which the curve shows no considerable shrinkage.

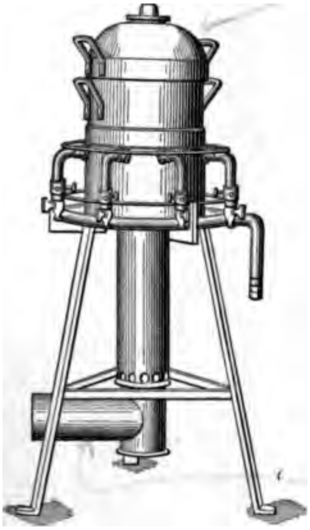


FIG. 98. — The Seger-Heinecke Furnace.

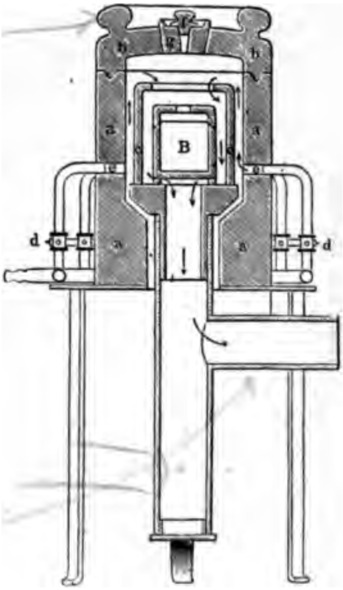


FIG. 99. — Section through the Seger-Heinecke Furnace.

After burning, the bars are transferred to an oven heated to 800° C. and allowed to cool slowly under factory conditions.

The resulting burned product is then tested for strength, porosity, specific gravity, abrasion and other qualities described later under "Testing of Refractory Materials."

If the clay be sufficiently promising to warrant further testing, shapes should be made in an auger machine. Such a machine is made by the firm of Mueller of St. Louis; it is provided with a number of moulds in which brick, tile and all shapes of solid and hollow ware may be made and then subjected to the more thorough tests described later.

To determine the temperature of softening alone it is necessary only to make a number of small-sized cones. Two or three are selected for each test, placed on a neutral and refractory plate and surrounded by a number of Seger cones of different numbers. The plate is then placed in a Deville furnace either of the original graphite-fuel, electro-resistance or oiled-fired type, and the temperature at which the cone of the material under examination turns down is determined by comparing it with the number of the Seger cone which softens at the same time. The Seger-Heinecke furnace is useful for this purpose. It is made as a crucible or a muffle furnace and heated by a series of gas burners of the Bunsen type. (See Figs. 98, 99, page 254.)

Testing of Refractory Brick and Raw Materials. — The ordinary commercial tests are of both chemical and physical character. The chemical analysis, in most cases, determines the content of silica, ferric and ferrous iron, metallic iron (which is present owing to the abraded particles from the crushers being intermixed with the batch), alumina, and the alkalis and alkaline earths.

In examining the rarer refractories, such as chrome brick and the artificial refractory products of Niagara Falls, other determinations are necessary.

Of the physical tests made the most important are: The test of the crushing strength, made on the side, on the edge and on the end of the brick; the specific gravity; the porosity in percentage of the volume and the absorption in percentage of the weight. Further tests of the abrasion, of the cohesion and of the expansion at high temperatures, and the permanent elongation or contraction after heating, should be made. Tests of conductivity are important, but demand more time and care than the ordinary laboratory can give.

For example, a test made on one of the leading brands of fire-clay bricks was tabulated as follows:

	Name.	Percentage loss on ignition.	
	xxx	0.07	

Chemical Analysis

SiO_2	Fe_2O_3	FeO	Fe	Al_2O_3	CaO	MgO	K_2O	Na_2O
per cent 54.44	per cent 2.53	per cent	per cent	per cent 46.01	per cent 0.18	per cent 0.53	per cent 2.24	per cent ....

Crushing strength, pounds per square inch.			Specific gravity.		Porosity, per cent vol.	Absorption, per cent weight.	Abrasion.
Side.	Edge.	End.	True.	Apparent.			
5098	3840	2693	2.34	2.03	12.93	6.36	cu. in. 0.12

Average permanent elongation per nine inches.	Expansion, meters per lin. ft.	Average temperature of test.	Maximum temperature.	Hours exposed to heat.
0.021	0.042	3016° F.	3157° F.	2½

It may be mentioned that building bricks are tested, as a rule, for crushing strength, transverse strength, absorption, resistance to freezing and thawing. The methods of testing building bricks are of importance to the maker and user of fire-clay bricks, and are described on account of their general interest.

The proposed standard specifications for building brick suggested by the American Society for Testing Materials are as follows:

"*Selection of Samples.* — For the purpose of tests, brick shall be selected by some disinterested and experienced person to represent the commercial product. All brick shall be carefully examined, and their condition noted before being submitted to any test.

"*Transverse Test.* — At least five bricks shall be tested, laid flatwise with a span of 7 inches, and with the load applied at midspan. The knife edges shall be slightly curved in the direction of their length. Steel bearing plates, about ¼ inch thick and 1½ inches wide, may be placed between the knife edges and the brick. The lower knife may rest on a wooden base-block, slightly rounded transversely across its top. The modulus of rupture shall be obtained by the following formula:

$$R = \frac{3\,We}{2\,bd}2,$$

in which e is the distance between supports in inches, b is the breadth and d depth of the brick in inches, and W is the load in pounds at which the brick failed.

"The half bricks resulting from the transverse test shall be used for the compression and absorption tests. One half shall be crushed in its dry condition; the other half shall be used for the absorption test and crushed while in its wet condition. No specimen shall be used if any part of the line of fracture is more than 1 inch from the center line.

"*Compression Test.* — Compression tests shall be made on half bricks resulting from the transverse test. To secure a uniform bearing in the testing machine, the bricks shall be bedded flatwise on blotting paper, heavy fibrous building paper or heavy felt. In case the bricks have uneven bearing surfaces, they shall be bedded in a thin coat of plaster of Paris. For the dry test, before applying the plaster of Paris, the bearing surfaces of the brick shall receive a coat of shellac. The machine used for compression tests shall be equipped with spherical bearing blocks. The breaking load shall be divided by the area in compression and the results reported in pounds per square inch.

"*Absorption Test.* — At least five half bricks shall be first thoroughly dried to constant weight, at a temperature of from 200 to 250° F., weighed, and then placed on their faces in water to a depth of 1 inch in a covered container. The bricks shall be weighed at the following intervals: ½ hour, 6 hours, and 48 hours. Superfluous moisture shall be removed before each weighing. The absorption shall be expressed in terms of the dry weight, and the balance used must be accurate to 5 grams.

"*Freezing and Thawing Test.* — In case the freezing and thawing test is desired, at least 5 bricks shall be thoroughly saturated by immersion in cold water, which shall be raised to 200° F. in 30 minutes, and then allowed to cool. The specimen shall be immersed in ice water for not less than 1 hour, weighed, then transferred to the refrigerator and supported in such a manner that all faces will be exposed. The specimens shall be subjected to a temperature of less than 15° F. for at least 5 hours; then removed and placed in water at a temperature of not less than 150° F., nor more than 200° F., for 1 hour. This operation shall be repeated 20 times, after which the bricks, still saturated, shall be weighed again. The character of the bricks shall be noted before and during the test, and all visible changes recorded. Immediately on completion of this test, the samples are to be thoroughly dried and subjected to the transverse and compression tests."

Professor Bleininger has made the following comment on the prevailing methods of testing fire brick and fireproofing.*

"The testing of fire bricks is still being carried on from the standpoint that a melting point determination of a small specimen in a small furnace will tell the whole story as to the quality of the product. Recent work, however, has shown that it is possible to determine the standing-up behavior of a fire brick in an arch or bench by testing it at an average furnace temperature under load conditions. Thus, a good fire brick placed on end in a furnace and heated up to 2460° F. should carry a load of 50 pounds per square inch without contracting more than ¾ inch to the average length of 9 inches. Work carried out along this line has shown the practical nature of such tests, and has differentiated poor from good materials. In figures **** two bricks are shown which have both been subjected to the above conditions. One of them has stood the test well, while the other has failed. The same bricks under practical conditions have been found to behave in the same way.

"Information is lacking also with regard to fireproofing. What properties must a material possess in order to be well suited for the protection of steel beams and girders? How porous must it be, and how well can it withstand heating and cooling? These are questions which must be solved in the future if clay fireproofing is to hold its superior place against cheaper substitutes such as concrete. There is no doubt but that clay fireproofing is pre-eminently suited for this purpose, and it remains only to show what clays are best and to what degree they should be burned, and how porous they should be kept. It will not do to substitute for this class of ware low-grade clays which themselves fuse at a low temperature. Such practice will invariably result in harm to this particular industry and to the clay industry as a whole."

Testing the Crushing Strength. — The methods proposed by the American Society for Testing Materials are generally adopted by sellers and purchasers of refractory brick in English-speaking countries. The German system is described by Kerl.† The solid and hollow bricks are cut into halves, and these halves are burned together with Portland cement in such a way that the two cut surfaces are on opposite sides of the cube. The cube is then dried and the surfaces exposed to the pressure are made even with cement. Ten sample cubes are laid close together on smooth board, which should be covered with zinc. They are held firmly between two planed boards which are screwed to-

* *Journal of Wisconsin Clay Manufacturers' Association*, 1910, p. 50.

† *Handbuch der gesammten Thonwaarenindustrie*, pp. 504, 505.

gether. These boards are about 1 mm. higher than the sample, and are planed parallel to the table. Cement is laid on the top of the samples up to the height of the boards. When the cement is dry the boards are removed and the samples separated from one another by a gentle stroke. The samples are reversed and the other surface is levelled with cement in the same way. After the cement surfaces have hardened they are polished and cleaned. In this way the pressure during the test will certainly be distributed evenly over the area of the surface receiving it. If to be tested dry, the samples are warmed to 50 or 60° C. Samples may be tested wet, or may be subjected to pressure after being frozen. An hydraulic or beam testing machine is used in determining the load which the samples stand before breaking.

Professor Bleininger *(loc. cit.)* concedes the theoretical superiority of this method, but maintains that, for practical purposes, it is better to test a half brick bedded on edge. "The failing point is distinguished sharply, which overcomes the objection to the old procedure. The natural objection to testing bricks on edge is the fact that they are not used in this position." However, all the tests are made for the basis of comparison only. In testing refractories it is still the rule to test them on all their sides, applying the load at the middle of the span.

Tests to Determine Abrasion. — These may be done on Bauschinger's grinding machine. This is a horizontal cast-iron plate, 2 feet 6 inches in diameter, revolving at the rate of 30 revolutions per minute. The test piece (a half brick) is secured so that the bottom is in contact with the rotating disc. Then a weight of 75 pounds is applied, the disc dusted with 20 grams of emery powder and revolved 22 times at the rate of 2 feet a second. Then more powder is dusted on the disc and revolved with intermissions for dusting until it has described 110 revolutions. The test piece is then weighed and replaced on the machine, which now makes 220 revolutions before the next weighing is done. After further testing it at 330 and 440 revolutions, the computation of the abrasion is made.

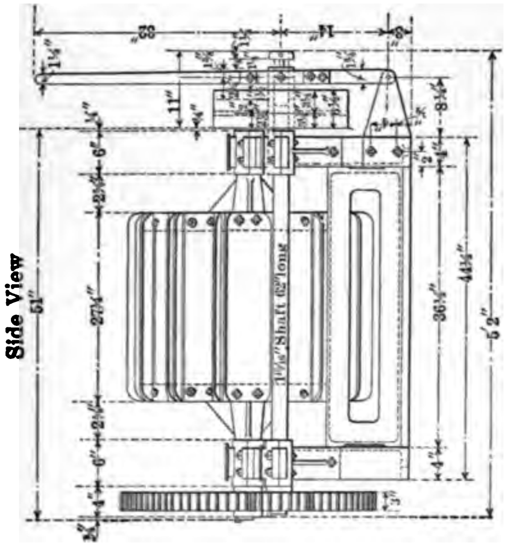
The sum of the weight lost in the four experiments may be called S. Then with the original specific gravity (by volume) of the piece called r, the abrasion will be represented by $\frac{S}{r}\cdot$

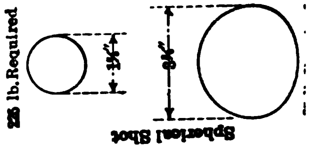
A test piece representing the second half of the brick may be subjected to the same test. The loss of weight may be called S. The final result, which shows the abrasion of the whole brick, will then equal $\frac{S+S}{2r}$.

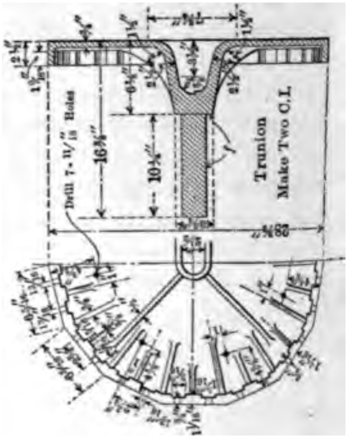
Wearing Test. — This may be done in a rattler or by the sandblast method. In the latter the test piece is subjected to the abrasive action of a blast at 20 pounds pressure of standard sand grain during a certain time. The relative depth of the abraded hole shows approximately the degree of resistance which the material offers to abrasion. The National Paving Brick Manufacturers' Association has made the following specifications for determining the abrasion: By revolving the brick or material in an iron barrel, with a certain definite number and weight of iron balls of prescribed size and chemical composition, for a fixed number and rate of revolutions and calculating the percentage weight of the loss by abrasion.

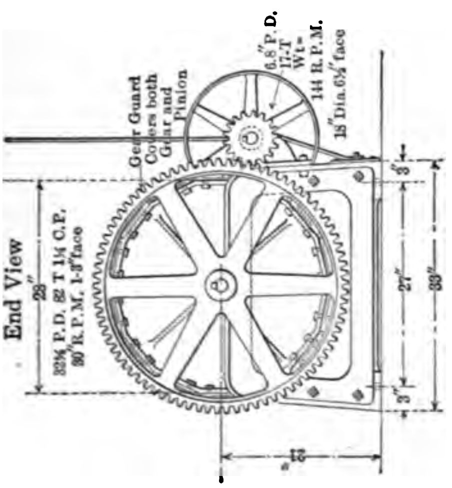
The Rattler. — The machine shall be of good mechanical construction, self-contained, and shall conform to the details of material and dimensions given below, and shall consist of barrel, frame and driving mechanism as herein described.

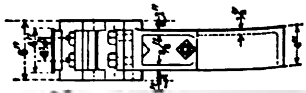
The Barrel. — The barrel of the machine shall be made of the heads, head liners and staves. The heads shall be cast with trunnions in one piece. The trunnion bearings shall not be less than two and one-half (2½) inches in diameter or less than six (6) inches in length. The heads shall not be less than three-fourths (¾) inch nor more than seven-eighths (⅞) inch thick. In outline they shall be a regular fourteen-sided (14) polygon inscribed in a circle twenty-eight and three-eighths (28⅜) inches in diameter. The heads shall be provided with flanges not less than three-fourths (¾) inch thick and extending outward two and one-half (2½) inches from the inside face of head to afford a means of fastening the staves. The flanges shall be slotted on the outer edge, so as to provide for two (2) three-fourths (¾) inch bolts at each end of each stave, said slots to be thirteen-sixteenths (13/16) inch wide and two and three-fourths (2¾) inches center to center. Under each section of the flanges there shall be a brace three-eighths (⅜) inch thick and extending down the outside of the head not less than two (2) inches. Each slot shall be provided with recess for bolt head, which shall act to prevent the turning of the same. There shall be for each head a cast-iron head liner one (1) inch in thick-

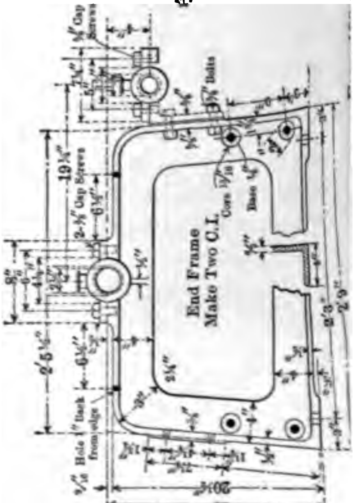

Side View
51″
1½″
22″
14″
8″
11″
27¾″
2⅜″
6″
4″
36½″
44½″
5′ 2″
1 ¹⁵⁄₁₆″ Shaft 62″ long
3″


25 lb. Required
Spherical Shot
3⅜″
5¼″


Trunion
Make Two C.I.
Drill 7 - ¹¹⁄₁₆″ Holes
16⅜″
10¼″
28⅝″
7⅜″
1⅛″


End View
23″
33¾ P. D. 82 T 1¼ C.P.
30 R.P.M. 1-3″ face
Gear Guard Covers both Gear and Pinion
6.8″ P. D.
17-T
Wt=
144 R.P.M.
18″ Dia. 6¼″ face
3″
27″
33″
21″




End Frame
Make Two C.I.
⅝″ Cap Screws
⅝″ Bolts
19¼″
2-⅝″ Cap Screws
6½″
2′ 5½″
Core ¹⁵⁄₁₆
Base ⅝″
⁹⁄₁₆″ Hole 1″ back from edge
20½″
21″
2′ 3″
2′ 9″

ness and conforming to the outline of the head, but inscribed in a circle twenty-eight and one-eighth ($28\frac{1}{8}$) inches in diameter. This liner or wear plate shall be fastened to the head by seven (7) five-eighths ($\frac{5}{8}$) inch cap screws, through the head from the outside. These wear plates, whenever they become worn down one-half ($\frac{1}{2}$) inch below their initial surface level, at any point of their surface, must be replaced with new. The metal of which these wear plates are to be composed shall be what is known as hard machinery iron and must contain not less than one (1) per cent of combined carbon. The faces of the polygon must be smooth and give uniform bearing for the staves. To secure the desired uniform bearing the faces of the head may be ground or machined.

The Staves. — The staves shall be made of six (6) inch medium steel structural channels twenty-seven and one-fourth ($27\frac{1}{4}$) inches long and weighing fifteen and five-tenths (15.5) pounds per linear foot.

The channels shall be drilled with holes thirteen-sixteenths ($\frac{13}{16}$) inch in diameter, two (2) in each end, four bolts to fasten same to head, the center line of the holes being one (1) inch from either end and one and three-eighths ($1\frac{3}{8}$) inches either way from the longitudinal center line. The space between the staves will be determined by the accuracy of the heads, but must not exceed five-sixteenths ($\frac{5}{16}$) inch. The interior or flat side of each channel must be protected by a lining or wear plate three-eighths ($\frac{3}{8}$) inch thick by five and one-half ($5\frac{1}{2}$) inches wide by nineteen and three-fourths ($19\frac{3}{4}$) inches long. The wear plate shall consist of medium steel plate and shall be riveted to the channel by three (3) one-half ($\frac{1}{2}$) inch rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced seven (7) inches from the center each way. The rivet holes shall be countersunk on the face of the wear plate and the rivets shall be driven hot and chipped off flush with the surface of the wear plate. These wear plates shall be inspected from time to time and if found loose shall be at once reriveted, but no wear plate shall be replaced by a new one except as the whole set is changed. No set of wear plates shall be used for more than one hundred and fifty (150) tests under any circumstances. The record must show the date when each set of wear plates goes into service and the number of tests made upon each set.

The staves when bolted to the heads shall form a barrel twenty (20) inches long, inside measurement, between wear plates. The wear plates of the staves must be so placed as to drop between the wear plates of the heads. These staves shall be bolted tightly to the heads by four (4) three-fourths ($\frac{3}{4}$) inch bolts, and each bolt shall be provided with lock nuts and shall be inspected at not less frequent intervals than every fifth (5th) test and all nuts kept tight. A record shall be made after each inspection, showing in what condition the bolts were found.

The Frame and Driving Mechanism. — The barrel should be mounted on a cast-iron frame of sufficient strength and rigidity to support same without undue vibration. It should rest on a rigid foundation and be fastened to same by bolts at not less than four (4) points.

It should be driven by gearing whose ratio of driver to driven should not be less than one (1) to four (4). The countershaft upon which the driving pinion is mounted should not be less than one and fifteen-sixteenths ($1\frac{15}{16}$) inches in diameter with bearings not less than six (6) inches in length and belt driven, and the pulley should not be less than eighteen (18) inches in diameter and six and one-half ($6\frac{1}{2}$) inches in face. A belt of six- (6) inch double-strength leather, properly adjusted, so as to avoid unnecessary slipping, should be used.

The National Paving Brick Manufacturers' Association will furnish without cost to all proper applicants the complete drawings of a machine which will meet the above specifications and requirements.

The Abrasive Charge. — (*a*) The abrasive charge shall consist of two sizes of cast-iron spheres. The larger size shall be three and seventy-five hundredths (3.75) inches in diameter when new and shall weigh when new approximately seven and five-tenths (7.5) pounds (3.40 kilos) each. Ten shall be used. These shall be weighed separately after each ten (10) tests, and if the weight of any large shot falls to seven (7) pounds (3.175 kilos) it shall be discarded and a new one substituted; provided, however, that all of the large shot shall not be discarded and substituted by new ones at any single time, and that so far as possible the large shots shall compose a graduated series in various stages of wear. The smaller spheres shall be, when new, one and eight hundred seventy-five-thousandths (1.875) inches in diameter and shall not exceed ninety-five-hundredths (.95) pounds (0.430 kilos) each in weight. Of these spheres so many shall be used as will bring the collective weight of the large and small spheres most nearly to three hundred (300) pounds, provided that no small sphere shall be retained in use after it has been worn down so that it will pass a circular hole one and seventy-five-hundredths (1.75) inches in diameter, drilled in a cast-iron plate one-fourth ($\frac{1}{4}$) inch in thickness or weigh less than seventy-five-hundredths (.75) pounds (or .34 kilos). Further, the small spheres shall be tested by passing them over such an iron plate drilled with such holes, or shall be weighed after every ten (10) tests, and any which pass through or fall below specified weight shall be replaced by new spheres, and provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective it shall at once be replaced.

(*b*) The iron composing these spheres shall have a chemical composition within the following limits:

Combined Carbon. — Not less than 2.50 per cent.
Graphitic Carbon. — Not more than 0.10 per cent.
Silicon. — Not more than 1 per cent.
Manganese. — Not more than 0.50 per cent.
Phosphorus. — Not more than 0.25 per cent.
Sulphur. — Not more than 0.08 per cent.

For each new batch of spheres used the chemical analysis must be furnished by the maker, or be obtained by the user, before introduction into the charge, and unless the analysis meets the above specifications the batch of spheres shall be rejected.

The Brick Charge. — The number of bricks per charge shall be ten (10) for all bricks of the so-called "block size" whose dimensions fall between from eight (8) to nine (9) inches in length, three (3) and three and three-fourths ($3\frac{3}{4}$) inches in breadth and three and three-fourths ($3\frac{3}{4}$) and four and one-fourth ($4\frac{1}{4}$) inches in thickness. No block should be selected for test that would be rejected by any other requirements of the specifications.

The bricks shall be cleaned and dried for at least three (3) hours in a temperature of one hundred (100) degrees Fahr. before testing.

The Test. — The rattler shall be rotated at a uniform rate of not less than twenty-nine and one-half ($29\frac{1}{2}$) nor more than thirty and one-half (30½) revolutions per minute, and eighteen hundred (1800) revolutions shall constitute the standard test.

A counting machine shall be attached to the rattler for counting the revolutions.

A margin not to exceed ten (10) revolutions will be allowed for stopping.

Stopping and Starting. — Only one (1) start and stop test is regular and acceptable.

The Results. — The loss shall be calculated in percentage of the original weight of the dried brick composing the charge. In weighing the rattled brick any piece weighing less than one (1) pound shall be rejected.

Porosity. — S. Wologdine and A. L. Queneau use the following method * to determine the porosity. The porosity is defined either by the volume of the pores expressed in percentage of the total volume, or by the ratio of the difference between the weight of the sample saturated with water and the weight of the same sample dried in a steam oven to constant weight; this ratio is given in percentage of the dry weight. Let P_s be the weight of a sample dried to constant weight; P_m the weight of the sample saturated with water; P_e the weight of the sample immersed in water.

Then according to the second definition the porosity P_p will be:

$$P_p = \frac{(P_m - P_s)100}{P_s}$$

and according to the first definition it will be:

$$P_v = \frac{(P_m - P_s)\,100}{(P_s - P_e) + (P_m - P_s)} = \frac{(P_m - P_s)\,100}{(P_m - P_e)},$$

where $P_m - P_s$ = volume of the pores,

and $P_s - P_e$ = volume of the matter without pores.

Knowing $P_s P_m$ and P_e the true density (true d) and the apparent density (apparent d) are easily obtained.

$$\text{True } d = \frac{P_s}{P_s - P_e}.$$

$$\text{Apparent } d = \frac{P_s}{(P_s - P_e) + (P_m - P_s)} = \frac{P_s}{P_m - P_e}.$$

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* *Electrochemical and Metallurgical Industry*, Oct., 1909.

To obtain P_s, P_m and P_a, three weighings are necessary; first, of the dry specimen; second, of the same specimen boiled in water to expel all the enclosed air and then cooled in water under reduced pressure; third, of the specimen saturated in distilled water.

The specimens used in these determinations were regular samples weighing about 10 gr. and broken from bricks; they were boiled in a beaker for an hour in distilled water; the beaker and contents were then allowed to cool under reduced pressure. If no air bubbles appeared during a second boiling, the sample after cooling was weighed in water by means of an hydrostatic balance. The specimen was then weighed in air in weighing bottles after carefully removing all superficial water with blotting paper; this determination of P_m was repeated several times; the different results were then averaged.

The Charlottenburg Reichsanstalt uses the following method to determine porosity and specific gravity.

G = the weight of the body in air.

G' = the weight of the body in water.

G_1 = the weight of the body under atmospheric conditions.

G_t = the weight of the body dried at 100° C.

G_p and G'_p = the weight S of the body covered with paraffin.

G_w and G'_w = the weight S of the body saturated with water.

J_m = the content of the body obtained in the determination of the volume by measurement; J_g = the content obtained by weight. Accordingly, $J_g = G_w - G'_w$, or $= G_p - \left(G'_p + \frac{G_p - G_r}{0.93}\right)$, where 0.93 is the specific weight of paraffin. Now let s indicate the true specific weight of the body, that is, in the form of powder, and r the apparent or volume weight of the body.

The specific gravity is determined by crushing and grinding the test piece. The powder must be homogeneous grains and have a mesh of a hundred. The powder is dried at 100° C. and its specific weight determined with Schumann's or Seger's volumeter.

The quotient of the weight of the dry powder and the volume it displaces gives the absolute specific weight of the material.

$$s = \frac{G_t}{J_m}.$$

To determine the apparent specific gravity or volume weight, pieces of approximately similar size are dried at 100 to 110° C.

Then the weight is determined either by the method of saturation with water or covering with paraffin. The former method is preferred.

The apparent specific gravity or volume weight $r = \frac{G}{J}$ and is derived as follows:

(*a*) Saturation method:

$$r_t = \frac{G_t}{G_w - G'_w}.$$

(*b*) Paraffin method:

$$r_t = \frac{G_t}{G_p - \left(G'_p + \frac{G_p - G_t}{0.93}\right)}.$$

The relation of the solid mass to the content of a brick of the density is determined.

$$d_t \text{ (density)} = \frac{r_t}{s}$$

and the porosity, called $u_t, = 1 - \frac{r_t}{s}$.

The nearer $\frac{r_t}{s}$ approaches 1 the denser the brick.

The water absorption $W_t = (G_w - G_t)\frac{r_t}{G_t}$, for the apparent or volume weight, and $W_t = \frac{G_w - G_t}{G_t}$, for the absolute specific gravity.[*]

Soluble Constituents. — Fire brick should not have any soluble constituents. Test pieces are ground fine (100-mesh) and boiled with distilled water for an hour. The insoluble matter is dried and weighed. The difference from former total weight gives the quantity in solution. The dissolved salts in the solution are determined by ordinary chemical analysis. Such soluble salts are generally sulphates of lime and magnesia.

Elongation under Heat. — The length of the test brick is measured with the calipers in four or five equidistant divisions. It is then set in a muffle or gas furnace and heated to the temperature at which it is to be used, and measured again and reheated until a constant figure of elongation is obtained. Generally 2½ or 3 hours for fire-clay bricks are sufficient. The elongation is expressed in inches per 9 inches or in inches per linear foot. Many fire-clay bricks, although showing considerable elongation when hot, show a contraction (after heating) when cold.

Tests of Resistance to Chemical Agencies. — This is discussed under "Testing of Refractory Raw Materials," page 272.

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[*] See Kerl, *Handbuch ger gesammten Thonwaarenindustrie*, pp. 497, 498.

Resistance to Heat. — The refractory must stand a temperature of at least 50° C. above that at which it is to be used. To determine the melting point sample pieces of a size about four cubic inches are cut and exposed to gradually increasing temperature in a gas muffle, or in a Deville or Heinecke furnace. The point of fusion is determined as the temperature at which the sample, or a broken piece of the sample, in case it breaks, begins to fuse, or when any constituent or constituents begin to flow molten out of the whole. Not only the outside, but the broken edges and surfaces, must show signs of distinct fusion. The experiment should be protracted at any temperature at which fusion may be expected for about 30 minutes.

A more detailed description of the method of determining the melting point is given under the "Testing of Refractory Raw Materials."

Determination of Volume.* — The change in volume, to be determined for getting the cubic shrinkage, is measured by means of a Seger volumeter. This consists of a four-liter, wide-mouthed, glass-stoppered jar. A circular opening in the center of the stopper is fitted with the ground end of a short glass tube *m*, which expands above into a bulb *b*, and is again contracted above it. The jar has a glass stopcock *e* near its base, which is connected above with a burette *a* of 125 c.c. capacity and graduated to tenths. The upper end of the burette also widens to a bulb *f*, from the top of which there extends a bent tube for the attachment of a rubber, this tube being used to draw the liquid into the burette.

When the stopcock in the lower part of the burette is open, and the liquid runs into the jar up to the mark on the small glass tube *m*, the liquid stands at the zero point in the burette.

The method of using the apparatus, which was developed in testing a number of Iowa clays, is as follows:

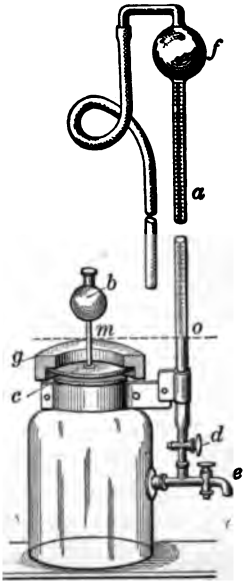

FIG. 104. — Seger Volumeter.

"To use the volumeter for determining the volume of clay, it is filled with oil (ordinary kerosene) with a specific gravity of 0.8 accurately known).

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* Ries, "Clays," p. 160.

"After filling the jar the burette is filled with the liquid by suction through the rubber tube, and held full by turning the burette valve or by means of a pinchcock on the rubber. The stopper is now removed and the test piece of the clay, which is still plastic and permeable to water, is carefully wiped dry of the coating film and put in. The test pieces, which are approximately 3 inches long, are allowed to dry until, on picking a piece up endwise between the thumb and finger, the middle portion does not sag. The point is noted carefully and all samples are treated exactly the same. Care is taken not to splash any of the liquid in placing the block of clay in the jar. In order to prevent this and to avoid breaking or otherwise marring the test piece by dropping it into the vessel, a small wooden float or support, by which the clay may be carefully let down into the liquid, is advantageous. This float is conveniently made with a small eye or hook near each end so that it may be handled by reaching in with two stiff bent wire rods. Some such arrangement as this is quite necessary in handling raw clays but can be dispensed with when the clays are burned. The stopper is now replaced, and by releasing the pinchcock the oil from the burette is allowed to flow back into the jar until it stands at the mark on the short tube.

"The volume of the clay is then indicated by the height of the liquid in the burette above the zero mark. The piece of clay is taken out and placed to dry while the volumeter is again filled to the zero point to be ready for the next test.

"When dry the clay is heated to 230° F. to expel all moisture, and after weighing it is placed in a vessel of oil until saturated. This requires from 3 to 6 hours for small test pieces of approximately 3 by 1½ by 1½ inches. When saturated the piece is again weighed and its volume measured as before. Having now the wet and dry volume the percentages of cubical shrinkage in drying are easily calculated."

In measuring fire shrinkage, the same test pieces are employed that were used in determining drying shrinkage. They are placed in a small muffle furnace and burned at a temperature of from 700° to 800° C. By burning at this heat, dehydration and oxidation of the clay are completed. It is about the temperature at which common, porous, red building brick is burned. For the large number of clays vitrification has not yet begun at this heat, and they are left in the most porous condition attained during any part of the burning process.

Testing of Raw Refractory Materials. — Tests are made to determine:

1. The infusibility.
2. The degree of firmness at high temperatures.

3. The resistance to action of chemical agents.
4. The degree of change of volume at high temperatures.
5. The shrinkage or expansion in drying and burning.
6. The effect of sudden change of temperature.
7. Mechanical qualities of strength and density.

Further, in the case of clays, (1) the degree of plasticity, (2) the bonding power, (3) the water required to attain maximum plasticity and (4) percentage of absorption after burning must be determined.

The determination of the melting point of refractory materials is done by exposing small three-sided pyramids, 2 cm. high and 1 cm. base of triangle or pyramid, to the action of the heat.

In the case of clays the pyramids or cones may be made of equal parts of burned and unburned material in order to reduce the degree of swelling and the formation of air bubbles.

It has been frequently observed that clays with a high melting point become soft at a relatively low temperature.

Cramer * proposes the following method for deciding on the choice of satisfactory refractory clays.

1. The Infusibility. — The first and most important condition for the successful preparation of refractory products is the employment of raw material with high degree of infusibility. This should withstand a temperature of at least 1650° (the fusing point of cone 26) in order to make a sufficiently refractory brick or vessel. All attempts to improve the quality of materials, especially clays and quartzites, which do not satisfy the heat test on account of a high percentage of fluxes, by treatment with acids to dissolve out the obnoxious alkalis and metal oxides, have proved commercially impossible and technically unsatisfactory.

In the determination of the melting point of the clay, dinas, quartz, magnesite, kaolin and other refractory raw materials and also finished products, small samples are exposed to heat in a Deville or Heinecke furnace or in a hot gas muffle. The samples are preferably made in the form of three-sided pyramids with a height of 2 cm. and a base side length of 1 cm. In the case of testing the finished product cubes may be taken should the work of fashioning the pyramids prove too difficult.

The samples are placed in a crucible of extremely refractory material, which is gen [illegible] fire clay, although magnesia and chromite are always tested in magnesia crucibles. The sample is heated carefully, the temperature being controlled by Seger cones. The Deville furnace is especially satisfactory. This consists of a hollow cylinder of refractory material supported on a thick wrought-iron plate. This plate has a hole in the middle about 3 cm. in diameter, and around it two rows of equidistant fine holes about 6 mm. in diameter. The cylinder is 35 cm. high and surrounded by an iron shell, which extends about 8 cm. below the wrought plate and rests on an iron disc supported on a tripod; a blast enters from a pipe into the bottom space of 8 cm. of the iron shell and thence is forced through the holes to the cylinder. The point of the iron shell with the supporting disc is made air-tight with sandy clay. The cylinder itself is conical and measures at the top 9 cm. and at the bottom 11 cm. clear in diameter. The lower half of the refractory lining is burned magnesite, the upper half consists of 90 per cent magnesia and 10 per cent kaolin.

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* *Thonindustrie Z* [illegible] 1902, pp. 300 and 1065.

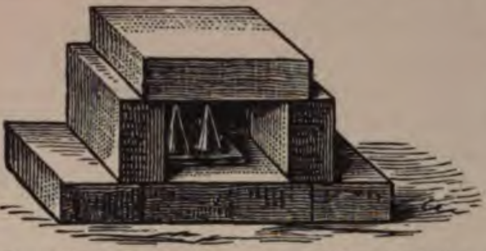

FIG. 105. — Testing Fusibility of Raw Materials Shaped into Cones.

The crucible in which the test is carried out is made of thoroughly burned chamotte, consisting of equal parts of alumina and the best kaolin, bonded and moulded with the necessary addition of pure kaolin. The crucible sets on blocks or a mass of refractory chamotte tested to cone 35 (1830° C.) without fusing. These crucibles for conducting the test are about 50 mm. (2 inches) high, 45 mm. (1¾ inches) wide and 5 mm. (⅕ inch) thick.

In carrying out the test the bottom of the crucible is covered to a depth of 7 mm. (⅓ inch) with a mixture of finely-screened alumina and kaolin. This is tamped firm and the sample placed upon it. The chamotte block on which the crucible sets is lowered by a tongs. The samples and Seger cones of approximately the same degree of fusibility as the sample are placed in the crucible, a Seger cone and sample alternating in a circle. The crucible is lowered. Now a fire is started by throwing ignited paper into the cylinder, turning on some blast and then adding 200 gr.

(½ pound) charcoal in the size of small nuts. Now some retort graphite is fed in the form of pieces about the size of a hazelnut. This retort graphite has little ash and makes a splendid fire. About 1 kg. (2½ pounds) of graphite are now fed in gradually during the course of the test. The condition of the Seger cones shows to what temperature the furnace was heated; that of the samples simply indicates their fusibility relative to one another.

2. Test pieces in the form of slabs (12 inches long by 1 inch wide by ½ inch thick) are laid on a porcelain plate in a muffle furnace and heated to cone 16 or 17 and then, supported on the two ends only on the edges of a plate, tested for softening and bending by reheating in the muffle. A porcelain plate such as that illustrated and described by Kerl * may be used. Cramer recommends heating and testing each slab as many as five times. Some clays bend only at the first test and improve in quality in the subsequent burnings; others bend more with every heat and some ultimately lie flat on the plate.

3. **Resistance to Chemical Agencies.** — These may be molten masses of basic or acid character, slags, volatile salts from fuel or furnace charges and fuel gases. The physical character is a factor as important as the chemical composition in determining the resistance of refractories to chemical agencies.

These tests are best made with the dried and burned ware in the vessel or furnace, and under the conditions in which the material will be later used.

In addition to the chemical and physical influences of slags, metals and gases, it is often forgotten that salts in dissociating and volatilizing attack the refractory linings of vessel. Instances † are given of a percentage of salt in coal, dissociating and attacking the lining with formation of sodium silicates, aluminates and chlorides. The former make easily fusible slags, the latter spongy excrescences on the brick.

The more porous a brick is, the more liable it is to be penetrated by destroying slags and gases, and these attack in particular the alumina and clay constituents of a brick and destroy more silicious material by making it swell. Constancy of volume at high and sudden changes of temperature, and the mechanical strength and density have been discussed under the tests of fire-clay bricks.

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* *Handbuch der Thonwaarenindustrie*, Fig. 352.

† *Thonindustrie Zeitung*, 1892, p. 231; 1898, p. 546; 1895, p. 412.

The compressive strength is always determined, the tensile strength less frequently.

The refractoriness of a material is determined by the quantity of foreign constituents present. For instance, the excess of silica in clays above that which goes into chemical combination to satisfy the alumina and fluxes, acts as a flux itself, and, along with the alkalis and metal oxides, reduces the refractoriness of the clay and sand and, particularly in the form of pure pebbles, is especially unsatisfactory in clays.

The fusion of the fire clays results from the formation of double silicates, alumina silicate and silicate of the so-called fluxes (lime, magnesia, iron oxide, potash).

Thus we arrive at the law used above for determining the refractory coefficient. We determine just the relation of the alumina to the fluxes and the relation of silica to the alumina, and, by dividing the latter into the former, obtain our scale, which in the case of refractory clays will read from 1½ to 14.

Bischof's formula is:

$$Q = \frac{\text{O in } Al_2O_3}{\text{O in RO}} \div \frac{\text{O in } SiO_2}{\text{O in } Al_2O_3}.$$

In this formula the O in RO must be multiplied by 3 to make it conform to the scale that he used and the O combined with the iron must be figured as being combined in the condition as FeO. Therefore the formula is better written:

$$Q = \frac{\text{O in } Al_2O_3}{3 \times \text{O in FeO}} \div \frac{\text{O in SiO}}{\text{O in } Al_2O_3} = \frac{(\text{O in } Al_2O_3)^2}{(3 \times \text{O in FeO}) \times (\text{O in } SiO_2)}.$$

Factors:

O in SiO_2 = per cent SiO_2 × 0.5298.
O in Al_2O_3 = per cent Al_2O_3 × 0.4696.
O in FeO = per cent Fe_2O_3 × 0.2000.
O in CaO = per cent CaO × 0.2853.
O in MgO = per cent MgO × 0.3971.
O in MnO = per cent MnO × 0.2254.
O in K_2O = per cent K_2O × 0.1698.
O in Na_2O = per cent Na_2O × 0.2571.

Another method of determining physically the refr value is given by Dr. Bischof. The melting point of clay is determined and its value called, say, 1. Then t be examined is shaped into a pyramid of approximately the size of that of the normal clay, and its melting point determined. Then certain quantities (from 1 to 10 times the weight of the pyramid) of sand are mixed with the clay to be examined. These are made into pyramids, and that mixture which behaves similarly to the normal clay is recorded, and, from the weight of sand added, its refractory coefficient may be determined. Should, for example, a clay need twice as much sand as its own weight to fuse like the normal clay, then its refractory coefficient would be 2, if three times as much is added, then its refractory coefficient is 3. Instead of making the scale 1 to 10, it is easier to make it 1 to 100. Then in the clays already considered:

I. Purest clay would be = 100.
II. Zettlitz clay would be = 60–70.
III. Belgium clay would be = 50.
IV. Grünstadt clay would be = 30.
V. Cassel clay would be = 20.

At the best, the method should be regarded only as indicating the possibilities of the clay and not regarded as absolutely infallible.

In the pyrometric examination of refractory quartzes which are generally accompanied by similar fluxes, a similar method is recommended by Bischof. He uses as normal quartz ground rock crystal and calls its refractory coefficient 100. A sandstone which requires one equal part of powdered rock crystal to induce behavior in high temperatures corresponding to the pure rock crystal is marked as (100 − 1) or 99. Another sandstone which would require 2 equal parts of powdered rock crystal would be classed as 98.

Measurement of Plasticity. — The degree of plasticity varies within very wide limits, and clays are classified as those which are lean or of low plasticity and those which are fat or highly plastic. Bischof, Zschokke, Grout and Ries all discuss methods of measuring the plasticity. The usual and easiest way is to test the clay between the fingers. Zschokke states * that it is necessary to consider three qualities in arriving at the degree of plasticity of a clay. These are (1) the property of d[illegible]ity, (2) its degree of cohesion and (3) its sti[illegible] Zschokke moulded

* [illegible] 0.

samples into forms 60 mm. high and 30 mm. in diameter, placed these in a specially designed machine and pulled them until they broke. The degree of deformability was determined by the elongation of the samples, while the force expended to rupture them denoted the tensile strength. The plasticity coefficient is obtained by multiplying the degree of deformability with the figure of the tensile strength. The following figures illustrate this:

Rupture Experiments

Sample.	Slow pull.			Jerky pull.			
	Tensile strength required per sq. cm. = β.	Deformability in per cent = L.	Plasticity coefficient = βL.	β	L	Plasticity coefficient = βL.	Per cent H_2O required.
A	0.63	70	44.1	1.73	127	220	29 S
B	0.20	86	17	0.76	73	55	23.9

All these results are modified by the fact that it is difficult to fix the degree of elasticity in the sample. The percentage of water has considerable influence in the plasticity. In very plastic clays there is some unknown chemical or physical attraction between the clay substance and admixed water, which is lacking in the flint and less plastic clays.

Jochum's method of determining the plasticity is very similar to that of Zschokke's. He uses a machine like a hanging scales and notes the weight or pressure required to make the clay samples break.*

Measurement of Shrinkage. — Shrinkage may be expressed in either linear or cubic terms. The former is given in percentage terms of the original length of the ware and is easily determined by direct measurement. To determine the cubic shrinkage in drying it is necessary to carefully determine the volume of the material when moist and again when dry, while the difference in volume between the latter and that of the burned clay gives the cubic fire shrinkage.†

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* This is described by Kerl, *Handbuch der gesammlen Thonwaarenindustrie*, p. 101, etc.

† Ries, "Clays," p. 160.

Standardization of Refractory Materials. — The English Ceramic Society has initiated a movement to standardize and grade refractory materials.. In Germany the firm of Cramer, which publishes the *Thonindustrie Zeitung* and conducts a laboratory and consulting office, has been the leader in grouping and standardizing these materials. In America there is still chaos in the classification as in England and France.

It has, therefore, been decided that a body called "The Center for the Standardization of Refractory Materials" should be formed which would complete the following program:

(*a*) To arrange and classify the various refractory materials.

(*b*) To arrange standard specifications for the raw materials and for the manufactured products.

(*c*) To consider the possibility of arranging for uniformity in certain "stock" or "standard" sizes.

(*d*) To agree upon standard methods of testing.

It is hoped that the specifications may become international, and the aid of German, French and American engineers is needed to insure the success of the plans.

Dr. J. W. Mellor, secretary of the English Ceramic Society, Stoke-on-Trent, is drafting a set of specifications for the standards.

CHAPTER XIV

THE THERMO-PHYSICAL PROPERTIES OF FURNACE MATERIALS

Thermal Conductivity and Resistivity. — Furnace operators and students frequently ask for information on the thermal conductivity of materials. Until quite recently all the available data were scattered, and the curious and interested would be referred to the works of Landolt and Boernstein, Peclet, Richards, Hering, Hutton and Beard, and Wologdine. Within the last two years so much interest has been stimulated in the questions of flow of heat through furnace walls and electrical, hot and cold insulation that considerable work has been done in determining the resistivity or conductivity of materials (such as that by Clement and Egy of the University of Illinois on the thermal conductivity of fire clay) and in correlating such results. Messrs. Hering, Queneau and others have been active in publishing the results of recent and previous experiments in *Metallurgical and Chemical Engineering* and in transactions of scientific societies.

In finding the relative conductivity of various materials Messrs. R. S. Hutton and J. R. Beard have used an apparatus devised by C. H. Lees and J. D. Chorlton.* A digest of the methods and results of their determinations of the insulating qualities of refractory materials is published in the *Electrochemical and Metallurgical Industry*, Vol. III, p. 291.

The conductivity,† K, is the quantity of heat in gram calories which is transmitted per second through a plate 1 cm. thick per square centimeter of its surface, when the difference of temperature between the two faces of the plate is 1° C.

The appended values of K apply to a temperature range from 20 to 100° C.; the materials were generally in the form of powder passed through a sieve with 600 meshes per square centimeter.

= 62 meshes per lin. inch.

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* *Philosophical Magazine*, June, 1896, p. 495.

† Note the small values for K compared with those in Chapter XIII (page 222) where the coefficient is expressed in kg. cal. per sq. per m. per hour degrees C.

Sand, White Calais	$K = 0.00060$
Carborundum, fine	0.00050
" coarse	0.00051
Quartz, enamel	0.00036
" fused	0.00039
Fire-clay brick	0.00028
Retort graphite	0.00040
Lime	0.00029
Magnesia, fused	0.00047
" Mabor brick	0.00050
" Calcined, Greek	0.00045
" " Veitsch	0.00034
" Pattenson's light-calcined	0.00016
Kieselguhr (infusorial earth)	0.00013

Yet it is not advisable to choose a material by reason of the above data alone. It is always necessary to know the physical behavior of such materials at high temperatures, such as their degree of shrinkage or expansion, their porosity and other properties.* Chemical action, such as oxidation, renders some insulators unsuitable. These considerations are discussed by Hutton and Beard, who also suggest that the transmitter of heat, such as a retort body, should be of different material to the insulator, such as the furnace wall, and propose certain methods of construction which would enable us to realize the value of certain insulating materials without risk of impairing these by too high or too long continued heating. For if materials shrink and become less porous they often decrease in efficiency as insulators. † Mr. Hering publishes the properties of many substances in terms of thermal resistivity.

In Vol. VII (*loc. cit.*), numbers 9 and 10, Mr. Queneau describes S. Wologdine's methods of determining heat conductivity, gas permeability and porosity. In summarizing the results he represents the conductivity in gram calorie seconds per cubic centimeter per 1° C. Accordingly, the figures in the scales of Queneau are the reciprocal of those of Hering.

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* The coefficient of diffusion (Temperaturleitungs-Koefficient) is represented by K, divided by the density times the specific heat.

$$D = \frac{K}{\text{density} \times \text{sp. heat}}.$$

† *Metallurgical and Chemical Engineering*, Vr

No. material.	Conductivity.		
	Gr. cal. sec. per cm.^{3} per 1° C.	Kg. cal. hour per m^3 per 1° C.	Relative conductivity.
			Per cent.
1 Graphite brick	.025	9.0	100
2 Carborundum brick	.0231	8.32	92.4
3 Magnesia brick	.0071	2.54	28.4
4 Chromite brick	.0057	2.05	22.8
5 Fire-clay brick	.0042	1.50	16.7
6 Checker brick	.0039	1.42	15.8
7 Gas-retort brick	.0038	1.36	15.2
8 Building brick	.0035	1.26	14.0
9 Bauxite brick	.0027	0.96	12.4
10 Glass pot	.0033	1.19	13.2
11 Terra cotta	.0023	0.84	9.3
12 Silica	.0020	0.71	7.8
13 Kieselguhr	.0018	0.64	7.1

The figures selected are representative of the ordinary commercial grade of refractory materials. The coefficients were determined for temperatures of 1000 to 1200° C.

Hering uses the thermal ohm to express that resistance through which 1 watt of heat flow will pass when the temperature drop is 1° C. Hence, if R is the thermal resistance in thermal ohms, W the flow of heat in watts and T the temperature in centigrade degrees,

$$W = \frac{T}{R}.$$

Again, if r is the specific thermal resistance in thermal ohms per centimeter cube, then

$$R = \frac{rL}{s},$$

in which L is the length and S the cross section of a thermal conductor.

To reduce a thermal conductivity in gram calories per second to the resistivity in thermal ohms, multiply the reciprocal of the conductivity by 0.2388, when both are for 1 cm^3. To reduce gram calories per second to watts, multiply by 4.186. In order to compare the thermal resistivities Mr. Hering called that of silver the unit and reduced all values in the various works consulted to figures relative to this base.

The data appended may be used for steam heat, refrigeration, etc., as well as for calculation of electric heat, by first completing the simple calculation in terms of watts flowing through the insulation and then turning these watts into horse power, square calories per minute or other expressions of energy.

For example, Watts × 0.00134111 = horse power.
Watts × 0.0568776 = B.t.u. per minute.
Watts × 0.0143329 = square calories per minute.

To reduce units in terms of 1 cm. cube to those for 1 inch cube, multiply by 0.393700 when they are resistivities, and by 2.54001 when they are conductivities. To reduce thermal conductivities given in terms of B.t.u. per hour per square foot surface, per inch thickness per degree F. to thermal ohm, inch cube units, multiply the reciprocal of that number by 273.013.

TABLE OF THERMAL RESISTIVITIES

Approximately in Order of Resistivity Temperatures in Centigrade Degrees

	Thermal ohms.		Reference.
	Inch cube.	Centimeter cube.	
Silver, 0°–100°	0.094	0.24	LB
Copper (electrode mean), 100°–197°	0.090	0.23	H
Copper (electrode mean), 100°–837°	0.11	0.27	H
Copper, 0°–100°, about	0.11	0.27	LB
Copper	0.13	0.32	LB
Copper, cast	0.12	0.29	CJ
Copper, rolled	0.11	0.28	CJ
Copper, rolled	0.13	0.32	WF
Aluminum, 0°–100°	0.27	0.69	LB
Graphite, Acheson (electrode mean), 100°–390°	0.28	0.71	H
Graphite, Acheson (electrode mean), 100°–914°	0.32	0.82	H
Brass, 0°–100°	0.36	0.92	LB
Iron (electrode mean), 100°–398°	0.28	0.71	H
Iron (electrode mean), 100°–398°	0.43	1.1	H
Iron, wrought	0.22	0.55	CJ
Iron, wrought, 0°	0.46	1.2	LB
Iron, wrought, 275°	0.76	1.9	LB
Iron, wrought	0.79	2.0	WF
Iron, cast	0.26	0.66	CJ
Iron, cast, 30°	0.63	1.6	LB
Steel	0.24	0.60	CJ
Steel	0.81	2.1	WF
Steel, various	0.81	2.1	LB
Steel, 10% manganese	3.0	7.7	LB
Platinum	0.25	0.63	CJ
Platinum, 18°–100°	[illegible]	1.4	LB
Platinum	[illegible]	2.9	WF

TABLE OF THERMAL RESISTIVITIES—*Continued*

Approximately in Order of Resistivity Temperatures in Centigrade Degrees

	Thermal ohms.		Reference.
	Inch cube.	Centimeter cube.	
Carbon (electrode mean), 100°–942°	0.72	1.9	H
Carbon (electrode mean), 100°–360°	1.05	2.7	H
Lead	0.33	0.83	CJ
Lead	1.10	2.8	WP
Lead, 0°–100°	1.2	3.0	LB
Plumbago brick, about 1000°	3.8	9.6	WQ
Carborundum brick, about 1000°	4.1	10.3	WQ
Mercury, 0°–50°	5.5	14.1	LB
Quartz, 0°	5.9	15	LB
Graphite (probably plumbago), 7°	8.0	21	LB
Retort carbon, 0°	9.1	23	LB
Magnesia brick, about 1000°	13	34	WQ
Stone, calcareous, fine	16	42	P
Chromite brick, about 1000°	16	42	WQ
Ice	16	42	LB
Boiler scale, 60°	17	44	LB
Marble, fine-grained, gray	9.8	25	P
Marble, coarse-grained, white	12	31	P
Marble, 30°	19	48	LB
Stone, calcareous, ordinary	20	51	P
Fire brick (probably room temperature)	21	53	D
Fire brick, about 1000°	22	57	WQ
Fire brick, mean for 500°–1300°	23	57	Z
Fire brick, mean for 0°–1300°	30	77	Z
Fire brick, about 400°–800°	44	112	CE
Fire brick, mean for 0°–500°	67	171	Z
Checker brick, about 1000°	24	61	WQ
Gas-retort brick, about 1000°	25	63	WQ
Slate, 94°	26	67	LB
Building brick, about 1000°	29	72	WQ
Class pot, about 1000°	35	89	WQ
Porcelain, 95°	38	96	LB
Firestone (Feuerstein)	39	99	LB
Terra cotta, about 1000°	41	104	WQ
Chalk (solid)	43	109	LB
Cement, Portland, neat, 35°	44	110	N
Cement, Portland, 90°	132	336	LB
Lava	47	120	LB
Silica brick, about 1000°	47	120	WQ
Kieselguhr brick, about 1000°	52	133	WQ
Baked clay, brickwork	57	140	P
Building brick wall, average, 8″ to 40″ walls	62	160	W
Water, room temperature	72	180	LB
Glass, 28°	87	220	LB
Plumbago, 20°–155°, 26.1% solid matter	96	240	O
Fine sand, 20°–155°, 51.4% solid matter	109	276	O
Coarse sand, 20°–155°, 52.9% solid matter	110	280	O

TABLE OF THERMAL RESISTIVITIES—*Continued*

Approximately in Order of Resistivity Temperatures in Centigrade Degrees

	Thermal ohms.		Reference.
	Inch cube.	Centimeter cube.	
Cork (solid)	131	333	LB
Plaster of Paris, 0°	105	266	LB
Plaster of Paris, 20°-155°, 36.8% solid matter	221	562	O
Slag concrete, 34.3 lbs. per cu. ft., 50°, 1 part by weight slag and 0.61 cement	178	453	N
Pumice stone, 18.2 lbs. per cu. ft., 50°	169	430	N
Pumice stone	187	477	LB
Pumice stone, 20°-155°, 34.2% solid matter	219	558	O
Brick dust, sifted	204	518	P
Asbestos, 20°-155°, 8.1% solid matter	139	353	O
Asbestos, 36 lbs. per cu. ft., 600°	166	422	N
Asbestos, 36 lbs. per cu. ft., 50°	221	562	N
Asbestos, with air cells	416	1060	S
Cardboard, below 0°	239	606	LB
Ebonite, 48°	251	637	LB
Petroleum, 13°	265	672	LB
Wood pine, parallel to fiber	313	796	LB
Many liquid compounds (hydrocarbons, oils, etc.), about	313	796	LB
Anthracite coal	317	803	LB
Chalk, 20°-155°, 25.3% solid matter	332	844	O
Very porous slag, 22.5 lbs. per cu. ft., 50°	356	905	N
Zinc, white, 20°-155°, 8.8% solid matter	398	1010	O
Fire felt, 21°-175°	418	1060	B
Gas works braize	440	1120	C
Infusorial earth (fossil meal), 21°-175°	415	1050	B
Infusorial earth, 20°-155°, 11.2% solid matter	435	1110	O
Infusorial earth, 20°-155°, 6% solid matter	472	1200	O
Infusorial earth, burned, 12.5 lbs. per cu. ft., 450°	263	675	N
Infusorial earth, burned, 12.5 lbs. per cu. ft., 50°	477	1220	N
Infusorial earth, loose, 21.8 lbs. per cu. ft., 350°	427	1090	N
Infusorial earth, loose, 21.8 lbs. per cu. ft., 50°	562	1430	N
Infusorial earth	745	1890	C
Magnesia, carbonate, 85%, 20°-188°, average	537	1370	S
Magnesia, calcined, 20°-155°, 28.5% solid matter	160	407	O
Magnesia, calcined, 20°-155°, 4.9% solid matter	544	1380	O
Magnesia, calcined, 20°-155°, 2.3% solid matter	554	1410	O
Magnesia, calcined, 21°-175°	[illegible]	[illegible]	B

TABLE OF THERMAL RESISTIVITIES — *Concluded*

Approximately in Order of Resistivity Temperatures in Centigrade Degrees

	Thermal ohms.		Reference.
	Inch cube.	Centimeter cube.	
Charcoal, pine, 20°-155°, 11.9% solid matter	494	1260	O
Charcoal, from leaves, 11.9 lbs. per cu. ft., 100°	537	1370	N
Charcoal, from leaves, 11.9 lbs. per cu. ft., 50°	603	1530	N
Charcoal	723	1840	C
Feathers, 20°-155°, 2% solid matter	577	1470	O
Sawdust, 13.4 lbs. per cu. ft., 50°	614	1560	N
Sawdust	620	1570	C
Sawdust, 13.4 lbs. per cu. ft., 50°	765	1950	LB
Cork, granulated and compressed, 20°-188°	467	1190	S
Cork, ground, 10 lbs. per cu. ft., 200°	614	1560	N
Cork, ground, 10 lbs. per cu. ft., 50°	797	2030	N
Air, 20°-155°	143	364	O
Air, 0°	1700	4320	LB
Cotton wool, 20°-155°, 1% solid matter	596	1520	O
Cotton wool, 20°-155°, 2% solid matter	659	1570	O
Cotton wool, 5.05 lbs. per cu. ft., 100°	572	1460	N
Cotton wool, 5.05 lbs. per cu. ft., 50°	627	1600	N
Cotton wool	830	2110	C
Cotton wool, loose	2170	5500	LB
Cotton wool, compressed	2810	7120	LB
Hair felt, 20°-155°, 9.2% solid matter	633	1610	O
Hair felt, 21°-175°	790	2010	B
Hair felt	865	2200	C
Hair felt, below 0°	1080	2740	LB
Lampblack, 20°-155°, 5.6% solid matter	697	1770	O
Fine quartz sand	718	1820	LB
Silk, 6.3 lbs. per cu. ft., 100°	662	1690	N
Silk, 6.3 lbs. per cu. ft., 50°	752	1920	N
Wool, sheep's, 20°-155°, 2.1% solid matter.	616	1570	O
Wool, sheep's, 8.5 lbs. per cu. ft., 50°	676	1720	N
Wool, sheep's, 8.5 lbs. per cu. ft., 100°	745	1890	C
Wool, sheep's	803	2050	N
Mineral wool, 21°-175°	737	1870	B
Mineral wool, 0°-18°	1010	2570	C
Hard rubber	1060	2680	LB
Wood, pine, radially	1070	2720	LB
Loose fibrous materials, 9°	1540	3920	LB
Flannel	2650	6720	LB

B — George M. Brill. *Trans.*, Am. Soc. Mech. Eng., XVI, p. 827. Coverings on 8-inch steam pipes.

C — J. J. Coleman. *Engineering*, Sept. 5, 1884, p. 237. Ice melted in cube surrounded with the materials. Temperatures 0-18° and 0-38° C. The values were given relatively to each other; to reduce them to absolute measure it is here assumed that the value for sawdust is 620, thermal ohm, inch cube units.

CE — Clement and Egy.

CJ — Calvert & Johnson. Relative values based on silver. Reduced here on the basis that the conductivity of silver is 1.0 in gram calories per second, centigrade, centimeter cube units.

D — Deprets. Hood, " Warming and Ventilating Buildings," p. 249. Given relatively to marble, here assumed to be 10 thermal ohms, inch cube, units.

H — Carl Hering. " The Proportions of Electrodes for Furnaces." (Table.) Paper read before the Am. Inst. Elec. Eng., March 31, 1910. Mean values when materials are used as furnace electrodes.

LB — Landolt & Boernstein tables. The values here chosen are mostly approximate means of the generally numerous and sometimes greatly differing values given by different observers. For the individual values and for the authorities see those tables. They also include values for very many other materials.

N — Wilhelm Nussel. *Zeit. Ver. Deut. Eng.*, June, 1908, p. 906, table, p. 1006. Materials were placed between two concentric metallic spheres or cubes. Heat generated electrically in interior. Temperature measured with thermocouples at numerous depths in the material after several days' heating. As here given they represent the resistivities at the temperatures stated, not the means over a range. Probably the best and most reliable determinations published. His conductivities are here assumed to be in terms of kilogram calories per hour, centigrade, meter cube, units; although not so stated directly in the original, it is undoubtedly what is meant. An abstract appeared in the *Eng. Digest*, August, 1908, p. 168, in which the units are reduced to thermal units, feet, inches and Fahrenheit degrees; the formula there given omits to say that it is necessary to multiply by the temperature also.

O — Prof. Ordway. *Trans.*, Am. Soc. Mech. Eng., Vol. VI, 1884–5, p. 168. Tested in plates 1 inch thick between two flat iron surfaces, one of them heated by steam, the heat emitted by the other being measured calorimetrically. Extended, carefully made researches; presumably very good values. There is an error in the heading in table VII; square inch should read square meter, as in the others.

P — Peclet. Box, " Practical Treatise on Heat." Presumably ordinary weather temperatures.

S — H. G. Stott. *Power*, 1902. Pipe coverings. 200 feet of 2-inch pipe heated electrically to constant temperature. Coverings were somewhat over 1 inch thick; they are here reduced to 1 inch. Heat transmitted to air, hence these resistances include that at the surface.

W — Wolff. *Jour. Frank. Inst.*, 1893. The transmission of heat from the interior to the exterior of buildings through the walls; hence ordinary weather temperatures. Prescribed by law by German Government for heating plants. Said to agree well with good American practice. The value here given is an average of all the individual ones, omitting the first one, which differed greatly from all the others.

WF — Wiedemann & Franz; relative values based on silver. Reduced here on the basis that the conductivity of silver is 1.0 in gram calories per second, centigrade, centimeter cube, units.

WQ — Wologdine, Queneau. The temperatures were about 1000° C.; the materials were those of commerce and do not refer to extra pure or to inferior grades. The present writer is of the opinion, based on the method used in the tests, that these values are probably too low.

Z — Source lost, but probably fairly good values.

For further information the reader is referred to *Metallurgical and Chemical Engineering*, September, 1909, p. 383; February, 1909, p. 72; December, 1911, p. 652.

Mr. Hering has correlated these results. Some of them will probably be changed when more thorough and more numerous determinations have been made.

Influence of Temperature. — In proportion as substances increase in conductivity, so thermal insulators decrease in resistivity at higher temperatures. Wilhelm Nussel, in *Zeit. Ver. Deut. Eng.*, June, 1908, finds that the thermal conductivity of such insulation increases at the rate of $\frac{1}{273}$ part for every degree centigrade above 0° C. This is of interest, but must be accepted with caution since, as Hering points out, materials would become, under this law, absolute insulators at ab

Much work is still to be done in this subject. The metallurgist and engineer needs, most of all, determinations of the resistivity at temperatures between 1200 and 2000° C. The results cited disturb some generally accepted theories of insulation. Thus, cold air at 0° C. is an excellent insulator, whereas air heated from 20 to 150° C. is a better conductor than sifted brick dust and about the equivalent in conductivity of warm cement.

Magnesia bricks are a good conductor, while a mass of calcined magnesia insulates fifty times as efficiently. All loose material must be tested at different temperatures to realize its efficiency, since, while the air in the pores increases in quantity and in conductivity, the whole mass insulates less efficiently the higher the temperature employed. Readers will probably learn more interesting facts from these qualities which are suggestive of change in many of our accepted maxims and axioms of furnace and fireproof construction.

Mr. Hering also discusses* the subject of contact resistances and heat emission from surfaces, and the influence of shape, joints of construction and other factors. He publishes lengthy and interesting tables† of flow of heat from solids to gases at certain temperatures (e.g., brick to air), of metal to water, water to metal to air, gas to metal to water (e.g., fire gases to boiler) and gas to metal to gas. Mechanical, chemical and electrical engineers are referred to these tables for interesting and useful information. Appended are a few examples of flow of heat through contact surfaces in thermal ohms per square inch:

SOLID TO GAS (° C.)

60°, surfaces of dynamos to air at 20°	100
90°, brick to air at 20°	112
220°, brick to air at 20°	74
1000°, graphite to vacuum	65.8
2600°, graphite to vacuum	28.6
927°, tungsten wire, 0.229 mm. diam. to hydrogen	2.0
1727°, tungsten wire, 0.0088 mm. diam. to hydrogen	0.26
Silver polished to air per degree difference	10300
Sheet iron polished to air per degree difference	2970
Sheet iron not polished to air per degree difference	483

METAL TO WATER (° C.)

143°, brass to water at 40° C.	0.154

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* *Metallurgical and Chemical Engineering*, January and February, 1912.

† Ibid., January, 1912, pp. 42, 43 and 44.

WATER TO METAL TO AIR	
107°, water to cast iron to air at 20° C.	258
GAS TO METAL TO WATER	
Fire gases to iron to steaming water (boiler) (approx.)	34
GAS TO METAL TO GAS	
107°, steam to bronzed cast iron to air at 20° C.	171

Diffusivity. — The property of diffusing and transmitting heat is dependent on the conductivity, the density and the specific heat of the body. Thus the coefficient of diffusivity (Temperaturleitungs coefficient) or $D = \frac{K}{WS_1}$.

Here W represents the density, S_1, the specific heat, and K, the conductivity in gram calories seconds per cm.^{3} per 1° C. In this way the following table has been prepared:*

Name of material.	Diffusivity.
Aluminium	0.83
Antimony	0.14
Cadmium	0.47
Copper	1.13
Bismuth	0.07
Gold	1.18
Iron	0.17
Lead	0.24
Magnesium	0.88
Mercury	0.03
Nickel	0.15
Platinum	0.24
Silver	1.74
Cast steel	0.12
Tin	0.38
Zinc	0.40
Air	0.18
Cotton	0.0009
Cork	0.001
Ebonite	0.001
Rock material (granite, etc.)	0.012
Ice	0.011
Concrete	0.006
Average damp soil	0.0049
Water	0.0014
Fire brick	0.0067
Building brick	0.005
Silica	0.003

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* Communication from ll, University of Wisconsin.

Conductivity, Density, Porosity and Permeability. — M. S. Wologdine, of the École des Mines, has contributed most valuable information on the subject of the physical properties of refractories and especially of changes in these at high temperatures. While it is true that most of his experiments were done at temperatures lower than those at which refractories are used and all under 1300° C., yet he has been able to teach us much about conductivity, porosity and permeability and the effect of heat in changing the *moduli* of these qualities possessed by certain refractories. A. L. Queneau deduces the following conclusions from Wologdine's work:

"(1) Proper regard being given to the fusibility of the brick, all terracotta, building bricks, fire bricks, have practically equal coefficients of heat conductivity. The coefficients are differentiated in this class of refractory materials solely by the temperature of burning and not by the character of the clays or by their chemical composition.

"(2) In all refractory materials, including the special bricks, such as chrome, magnesia, carborundum and graphite, the heat conductivity is a direct function of the temperature of burning. I am inclined to include, as subject to this rule, the amorphous carbon and the graphite electrodes, though this has not yet been confirmed by actual determination to my knowledge.

"(3) The great value of silica bricks for heat insulating purposes, when burned at a moderate temperature, 1050° C., is due to the fact that their coefficient of heat conductivity is practically equal to that of Kieselguhr bricks and only one-half that of clay bricks.*

"(4) The unique characteristic of chrome bricks is that their coefficient of heat conductivity is independent of the temperature.

"(5) There are remarkable and often enormous variations in the permeability to gases of the same bricks with the increase in temperature. In one instance the permeability changed from 3.3 liters per hour to 241 liters per hour. This shows the importance of scientifically selecting the clay mixtures for a given work as for crucibles or retorts where, as in zinc metallurgy, the permeability to gases has a material influence on the metal recovery. In this connection the nil permeability of graphite crucibles is to be noted. Perhaps the same results might be obtained at a much reduced cost by substituting clay flakes for the graphite flakes as proposed by H. Putz.†

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* This deduction of Mr. Queneau is open to the criticism that the heat conductivity of silica bricks and of fire bricks varies greatly, depending on the physical properties of the brick. It is desirable that further [illegible] be made in this by independent observers.

† German patent 198, 840, Sept. 29, 1907.

"(6) To secure efficient heat insulation refractory materials should be burned at the lowest allowable temperature. This burning temperature is generally known; it is the maximum temperature to which the bricks will be exposed in the furnaces. The use of the maximum temperature is necessary in order to prevent the brick from shrinking any further when set in the furnace walls. Though this last fact is well known it is often neglected, and a shortening of the furnace life is the result.

"(7) The gas permeability of the bricks of blast-furnace linings must have an important bearing on their life, owing to the destructive action of carbon monoxide in contact with the iron oxide present in the brick.*

In conducting the tests to determine the heat conductivity, round flat plates were made from various batches of refractory materials. These batches represented the current commercial brick and retort mixtures. The plates were about 160 mm. (6 inches) across and 50 mm. (2 inches) thick. Four series of holes, three in each, were pierced in or through the plates. The first hole extended 5 mm. (⅕ inch) from the top, the second 45 mm. (1⅘ inches) and the third pierced the whole 50 mm. (2 inches). After being used in the conductivity test the plates were cut and cylinders 45 mm. in diameter and 50 mm. thick were made from them and used in the determination of the density, porosity and permeability.

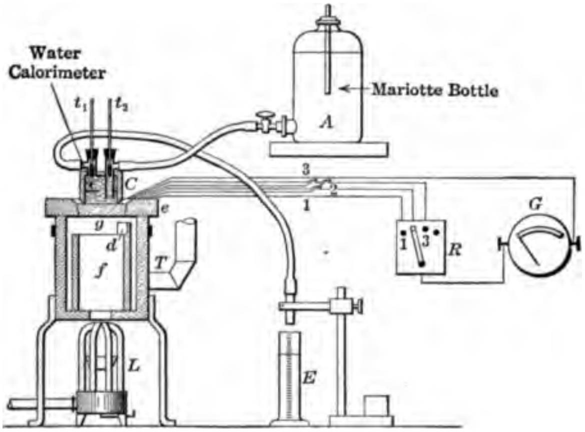

FIG. 106. — Determination of Heat Conductivity.

The test plate was placed in a gas furnace and the heat it attained measured [illegible] calorimeter. Temperature determin[illegible] the points, 5 mm. and 45 mm.

[illegible] 1907, p. 1627.

from the top surface and at the bottom surface which was directly exposed to the gas flame, by means of thermocouple pyrometers. It was thus possible to establish the relation between the heat flow and the heat gradient in the interior of the plate and to calculate the coefficient of heat conductivity, i.e., the quantity of heat expressed in gram calories passing in one second through a section of 1 sq. cm. with a variation of temperature of one degree per centimeter of depth.

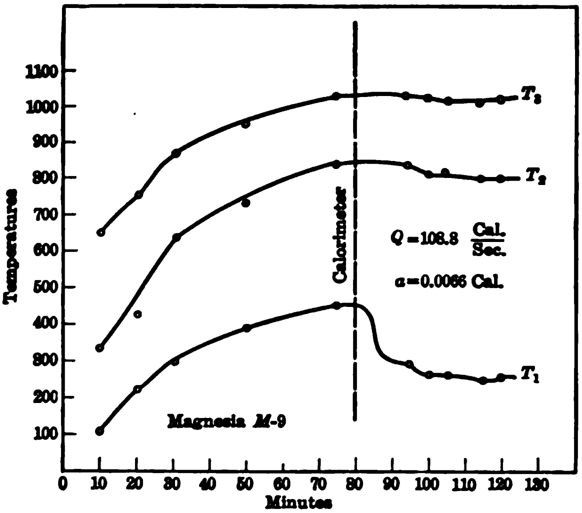

FIG. 107.—Temperature Variations During a Test of a Magnesia Brick.

The calculation for the determinations of the coefficient of heat conductivity for the test pieces is as follows:

Let T_1, T_2 and T_3 represent the temperatures given by the thermocouples, t_1 and t_2 the temperatures of the water as it enters and leaves the calorimeter, P the quantity of water in grams which passed through it every minute.

By interpolation the temperatures T_0 and T_5 of the upper and lower faces are obtained. The quantity of heat Q traversing per second an area equal to that of the calorimeter bottom is:

$$Q = \frac{P(t_2 - t_1)}{60}.$$

The coefficient of heat conductivity is:

$$a = \frac{S\,(T_5 - T_0)}{QL},$$

S being the area of the bottom in square centimeters and L the thickness of the plate in centimeters.

In the test given, in Figs. 107, 108, of a magnesia brick,

$T_1 = 265°$, $T_2 = 807°$, $T_3 = 1020°$ (temperature of furnace),
$t_1 = 14.9°$, $t_2 = 21.3°$, $L = 5$ cm., $S = 125$ cm.^{2}, $P = 1020$ gm.,

then $Q = 108.8$ gram calories and
$a = .0066$ gram-calorie units of conductivity.

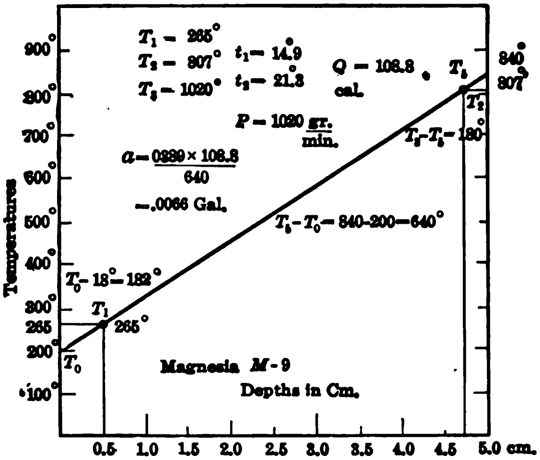

Fig. 108. — Test of Magnesia Brick.*

Wologdine finds that the conductivity of fire bricks increases with the temperature of burning, e.g., bricks (a) burned at 1050° C. had a conductivity of 0.0037 gram calorie; and bricks (b) burned at 1050° C. had a conductivity of 0.0035 gram calorie; while bricks (a) burned at 1300° C. had a conductivity of 0.0051 gram calorie; and bricks (b) burned at 1300° C. had a conductivity of 0.0042 gram calorie.

Again plates from gas retort mixture gave these results.

Temperature of upper surface.	Temperature of lower surface.	Conductivity, gram calories.	Temperature of upper surface.	Temperature of lower surface.	Conductivity, gram calories.
140	1120	.0040	140	990	.0038
175	1110	.0040	151	870	.0037
160	1050	.0039	105	685	.0035
150	1010	.0040			

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* *Electrochemical and Metallurgical Industry*, 1909, Vol. 7, p. 385.

This shows clearly the increase of the heat conductivity with the temperature. Similar tests were made with all refractory materials; all behaved in the same general way with the exception of chromite, whose heat conductivity is independent of temperature. Yet the degree of increase in conductivity varies in all materials. For instance, carborundum burned at 1300° C. has five times the conductivity of that burned at 1050° C., while magnesia increased only 5 per cent in the same range of temperature.

Mixtures with a clay basis, when burned at 1030° C., have an equal coefficient of conductivity in metric units of about 0.003. When burned at a higher temperature than that of 1300° C. the coefficient is notably higher, namely, 0.0045. Silica brick have a lower conductivity than the clay bricks if burned below the temperature at which quartz is transformed into trydimite. The conductivity of magnesia brick is about double that of clay bricks. Graphite and carborundum bricks have a conductivity nearly five times that of clay bricks. Finally, kieselguhr brick has the lowest heat conductivity coefficient, 0.0018, i.e., equal to only half that of clay brick. The conductivity always increases with the temperature whether that be obtained in the burning kiln or in the industrial furnace.

Conductivity, Density, Porosity and Permeability of Refractory Materials

Material.	Conductivity.		Density.		Porosity in per cent of vol.	Permeability.		Temperature of burning.
	Gm. cal. per sq. cm. per cm., per 1° diff.	Kg.-cal.-hr. per sq. m. per m. per 1° diff.	True δ.	Apparent δ.		Cm.^{3} sec. per sq. cm. per cm.	Lit. hr. per sq. m., per m.	Deg.
Fire clay brick	.0037	1.32	2.61	1.81	30.8	.0409	14.72	1050
Fire clay brick	.0050	1.81	2.05	1.91	24.1	.069	24.84	1300
Checker brick	.0039	1.42	2.65	1.91	27.8	.0465	16.74	....
Bauxite brick	.0033	1.19	3.12	1.92	38.4	.212	76.39	1300
Silica brick	.0020	0.71	2.75	1.58	42.58	.0092	3.32	1050
Silica brick	.0031	1.12	2.62	1.50	42.9	.0536	192.9	1300
Magnesia brick	.0065	2.35	3.39	2.0	41.0	.0097	3.49	1300
Magnesia brick	.0058	2.08	3.07	2.0	35.1	.517	186.1	1050
Carborundum brick	.0033	1.20	3.02	1.96	35.2	.0053	1.90	1050
Carborundum brick	.0145	5.22	2.83	1.96	30.6	.0043	1.55	1300
Chromite (unburned)	.0057	2.05	4.60	3.19	21.3	.0568	20.45	....
Chromite with clay binder (brick)	.0034	1.23	3.38	2.49	26.4	.0075	1.7	1300
Kieselguhr	.0018	0.64	2.48	1.03	38.0	.0957	34.45	....
Graphite brick	.024	8.64	2.42	1.79	26.0	.000	0	....
Porcelain	.0046	1.66	....	....	....	....	....	1400
Building brick	.0037	1.34	2.56	1.90	25.7	.0015	0.53	1050
Light clay	.0024	0.86	2.60	1.41	45.7	.0164	5.90	....

Density. — In a similar way the property of density varies with high temperatures, but this does not increase as the conductivity, but naturally diminishes the higher the temperature to which the refractory is heated. The density of silica brick burned at 1050° C. was 2.75; it became 2.62 at 1300° C., and 2.57 after long heating at 1400° C.

This increase in volume is due to the allotropic transformation of the quartz in trydimite. The change in density is accompanied in the case of the silica brick by only a slight change in porosity.

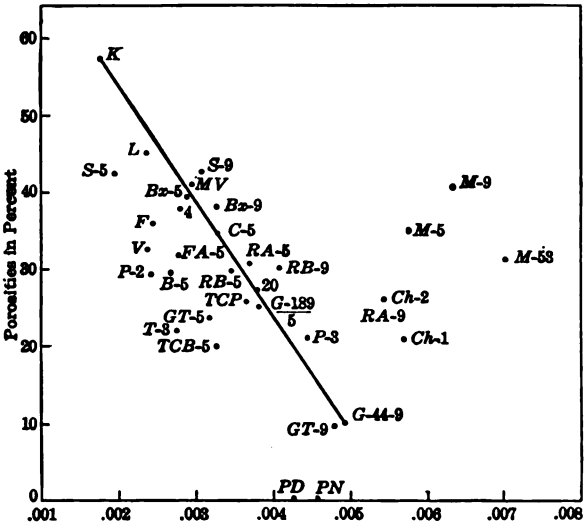

FIG. 109. — Conductivity (Abscissæ) and Porosity (Ordinates) of Different Bricks.

With the pure magnesia brick a marked change in porosity accompanies the change in density. The density 3.07 of the magnesia burned at 1050° C. becomes 3.39 when burned at 1300° C. The accompanying table shows the various changes in density, conductivity, porosity and gas permeability which accompany the changes in temperature of heating and burning.

Permeability. — In regard to permeability the size of grain and other physical conditions influence this property. Thus * granite bricks with a rather high porosity (25 to 28 per cent) are practically impermeable to gases, proving that the pores are numerous but very small. Silica bricks burned at 1050° C. have a permeability of 3.3 liters per hour, but at 1300° C. their permeability is 192 liters and at 1400° C. it is 241 liters per hour.

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* *Electrochem*[illegible]y, Vol. 7, p. 433.

Fire-clay and bauxite bricks behave in a similar manner.* With all fire clay and silica refractories the law holds "that the heat conductivity of refractories is that of the † air enclosed in the pores and not that of the clay material itself."

Chromite, magnesia, carborundum and graphite do not obey this law. See Fig. 110. The following table illustrates the way the permeability and conductivity increase with the porosity. The conductivity increases when the enclosed air bubbles have the greatest maximum mobility, i.e., when the permeability is greatest.

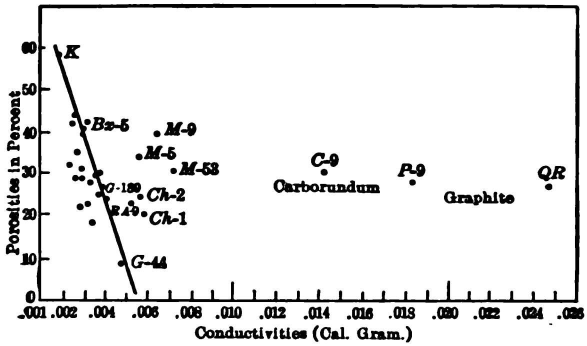

FIG. 110. — Graphite, Carborundum, Magnesia and Chrome Bricks (other than Clay Refractories) do not obey the Law that Conductivity increases with Porosity.

Permeability and Conductivity

Material.	Porosity.	Permeability in L. per hr. per sq. m.	Conductivity kg. cal. per hr. per sq. m.
Glass pot, P-2	30.0	0.30	0.89
Glass pot, B-5	30.4	1.02	0.96
Fire brick, RB-5	29.44	37.84	1.25
Fire brick, RA-5	30.85	14.72	1.32
Fire brick, RB-9	30.2	106.2	1.50

Taking bricks of a like porosity, for example, 30 per cent, Fig. 109 (P-2, B-5, RB-5, RA-5, RB-9), it is seen that the permeability increases with the conductivity.

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* *Electrochemical Metallurgical Industry*, Vol. 7, p. 436.

† Simonis and Wologdine.

The silica bricks with an equal porosity, 42 per cent, Fig. 109, appear to justify the same conclusion.

Material.	Porosity.	Permeability in L. per hr. per sq. m.	Conductivity kg. cal. per hr. per sq. m.
Silica brick, S–5	42.58	3.32	.71
Silica brick, S–9	42.90	192.9	1.12

The Measurement of Permeability.[*] — The permeability varies in a marked degree when the other physical properties vary but slightly; this is to be explained by the relatively large changes in the dimensions of the capillary pores due to the allotropic transformations of the clay, silica, magnesia, etc., which changes are usually followed by increase or decrease in the density.

The gas permeability is not a constant for a given specimen, as it varies with the different axes. The permeability in an axis normal to the face of a plate is different from that in an axis parallel to the surface.

This phenomenon prevented the use of a very simple measuring method which consisted in the determination of the volume of air passing in a given time, through the thickness of the plate, when a known gas pressure is maintained in a tube applied to the surface of the brick under test.

By comparing the figures so obtained with the results of the determination made on small cylinders cut out of the same plates and enclosed in a glass tube, it was found that the ratio between the two sets of figures was so large as to exclude the influence of experimental errors.

Permeability to Gases

Material.	Permeability Lit. sec.	Ratio.
Silica (S–9), directly	.109	...
Silica (S–9), in the cylinder	.302	3.4
Bauxite (Bx–9), directly	.044	...
Bauxite (Bx–9), in the cylinder	.0127	3.5
Bauxite (Bx–5), directly	.0054	...
Bauxite (Bx–5), in the cylinder	.0018	3.1
Fire brick (RB–5), directly	.016	...
Fire brick (RB–5), in the cylinder	.0063	2.5
Fire brick (RA–5), directly	.0069	...
Fire brick (RA–5), in the cylinder	.0025	2.8
Magnesia (M–53), directly	.0016	...
Magnesia (M–53), in the cylinder	.0009	1.7

[*] **Wologdine and** *ochemical and Met. Industry.*

In the preceding table are given the results obtained by the two methods.

It was thus necessary to select the second method, though it necessitated a long and tedious preparation of the specimens. Cylinders were cut about 40 mm. in diameter and of the thickness of the plates; a coating of paraffin was applied to the cylindrical surface, leaving exposed the two parallel faces. It was necessary to avoid all air bubbles between the specimen and the paraffin and to prevent at the same time any penetration of the paraffin in the pores of the cylinder.

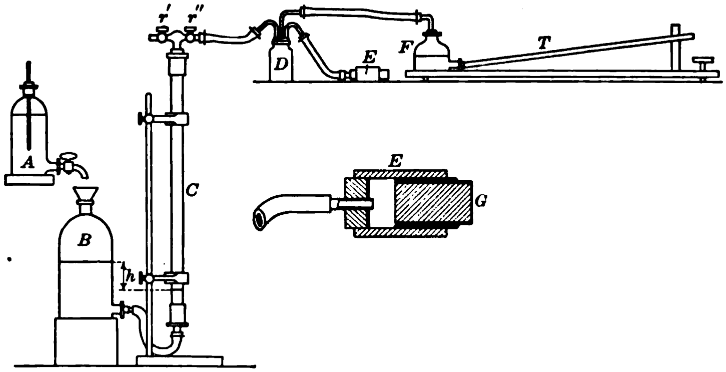

FIG. 111. — Apparatus for Determining Permeability.

This was best attained by rubbing the cold cylinders with a piece of paraffin just about to solidify.

Thus prepared, the cylinder is introduced into a glass tube, the joint between the glass and the cylinder being carefully luted with paraffin to avoid any leaks when gas pressure is applied in the tube, the other extremity being closed by a rubber cork provided with a small glass tube.

In Fig. 111 is shown the apparatus used with bricks of small permeability.

The cylinder *C*, 55 mm. in diameter and of about 2 liters capacity, graduated in cubic centimeters, served to measure the volume of air passing through the brick "*G*" in a given time.

The cylinder *C* was connected at its lower extremity with a bottle *B*, which received the water flowing from a Mariotte bottle *A*; the upper extremity of *C*, provided with two cocks *r'*, *r''*, was connected with a flask *D*, which in turn was in communication with the tube E, holding the brick cylinder under test G, and with a manometer F, the tube T of which was inclined to a slope of 1 in 10.

For bricks of great permeability the tube C was replaced by a large gasometer graduated in liters.

Tests were conducted as follows:

The bottle B is lowered with cock r' open, thus filling C with air, r' is then closed and B raised to a height h, this giving a pressure p in the cylinder E; the pressure is measured by the manometer F; as the air passes through E, the head h decreases; to maintain it constant, water is allowed to flow from the Mariotte bottle A.

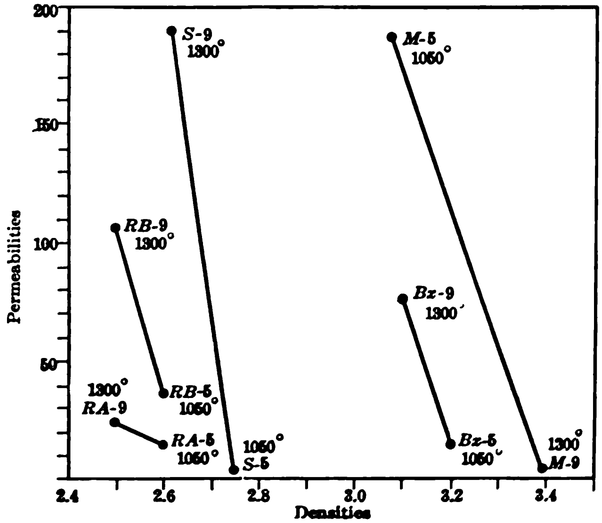

FIG. 112. — Permeability as a Function of Density.

When a state of equilibrium has been established the level of the water in the manometer T remaining constant, readings are taken of the water levels in C. To detect any leaks through the paraffin coatings the tests were repeated at least twice. For most of the bricks additional determinations were made by reversing the direction of the gas flow through the cylinders G, by turning them end for end in the glass holder E. All tests were repeated until concordant figures were secured.

The coefficient of permeability r is the quantity of air in cubic centimeters passing under a head of 1 cm. of water in one second through a cylinder of 1 sq. cm. [illegible] section and 1 cm. in height.

For practical applications the coefficient v may be better expressed by the number of liters passing in one hour through a surface of 1 sq. cm. meter thick; this new coefficient is V.

Let g be the quantity of air in liters passing t minutes under the pressure p–p_0 (p_0 being the height of water in the manometer tube T corresponding to the atmospheric pressure) through the cylinder of cross section s and length l.

The coefficient of permeability will then be:

$$v = \frac{1000\,gl}{t\,(p - p_0) \times 60\,S} = \frac{16.667\,gl}{t\,(p - p_0)\,S}.$$

Fig. 112 shows the relation of permeability to density.

Flow of Heat through Furnace Walls. — The quantity of heat Q' flowing through a given wall of a furnace of almost any character is proportional to the difference in temperature, T_1 and T_2, of the two faces of that wall. For a given difference in temperature Q' is inversely proportional to the thickness r. The heat flowing through a section of the wall is proportional to the area A of that section. Q' is necessarily proportional to the time t, over which measurements are taken.

Therefore, $$Q' = K\frac{T_1 - T_2}{r}At.$$

K is a constant, the thermal conductivity of the material. If Q' is expressed in calories, T_1T_2 in centigrade degrees, A in square centimeters, r in centimeters and t in seconds, then K will be in calorie seconds.

Messrs. Ray and Kreisinger* in testing the flow of heat through furnace walls reached the conclusion that in furnace construction a solid wall is a better heat insulator than a wall of the same total thickness containing an air space. The air space is less insulating the nearer it is to the hot interior face of the wall, and the closer it is to highly heated bodies. Should it be desirable to build the walls in two parts to minimize the formation of cracks by the expansion of the brickwork, the interlying space should be filled in with some loose solid insulating material such as ash, crushed brick or sand. However, when heat at low temperature is to be insulated, it is perfectly correct and advisable to use air space.

The quantity of heat flowing by conduction from one plane to another through any portion of the furnace wall depends upon

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* *Bulletin* 8, Bureau of Mines, 1911.

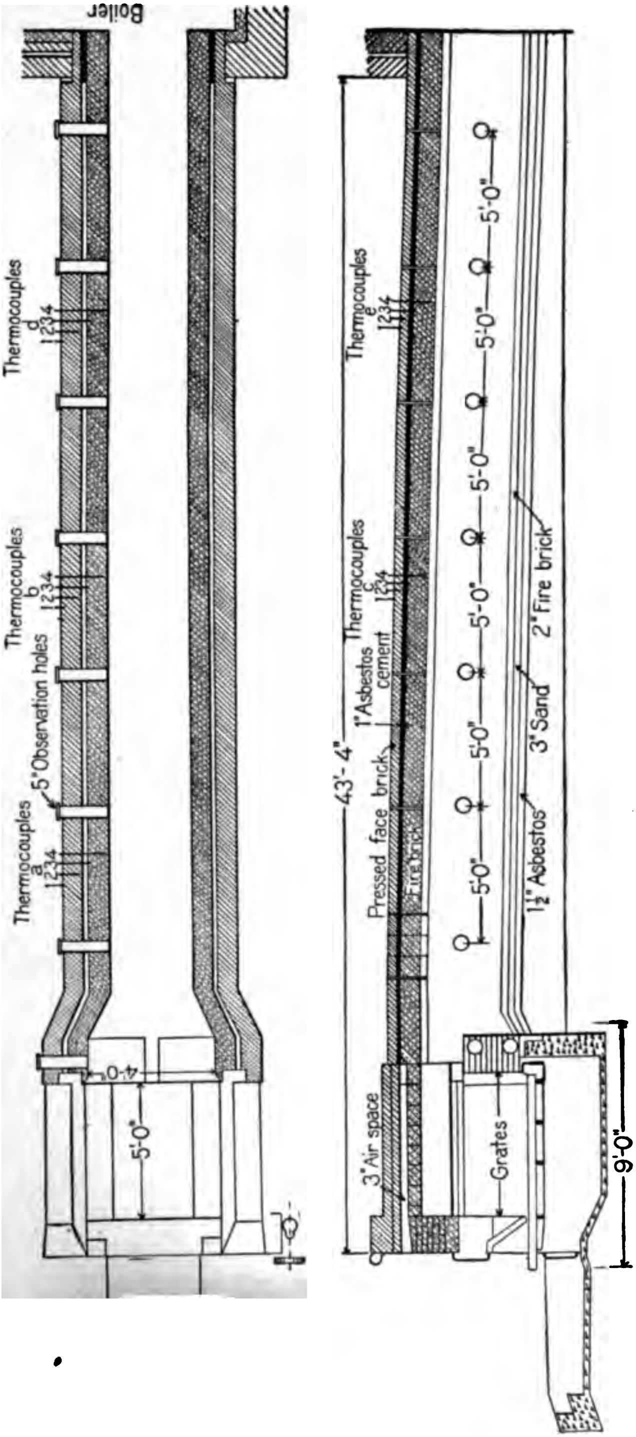
Boiler
Thermocouples d 1234
Thermocouples b 1234
5" Observation holes
Thermocouples a 1234
4'-0"
5'-0"
Thermocouples e 1234
Thermocouples c 1234
1" Asbestos cement
Pressed face brick
Fire brick
43'-4"
5'-0"
5'-0"
5'-0"
5'-0"
5'-0"
5'-0"
2" Fire brick
3" Sand
1½" Asbestos
3" Air space
Grates
5'-0"
9'-0"

FIG. 113.

the difference of temperature between these two planes and upon the resistance to the heat flow. With the same temperature difference, if the resistance is high, a small quantity of heat flows through; if the resistance is low a large quantity flows through. Or, if the quantity of heat is to remain constant the temperature difference must be large if the resistance to the heat flow is high, and small if the resistance is low.

So, in the case of the furnace wall, where the quantity of heat passing between any two planes which are parallel to the surfaces of the walls is the same, the temperature difference between any two planes indicates the resistance which the material or space between the two planes offers to the flow of heat. For example, if the temperature difference between the faces of the fire-brick wall is high, it may be said that the resistance of the material of the wall is high, or, if the temperature difference between the two surfaces on each side of the air space is low, it may be inferred that the resistance to the heat passage across the air space is low. Thus it is possible to rely on the temperature difference as being a true indicator of high or low resistance to heat flow between any two planes which are parallel to the surface of the wall.*

From numerous experiments it was found that the average temperature drop through the 9-inch fire-brick portion of the roof of the furnace was 350° C., through that of the side wall (9 inches) about 450° C.† Accordingly the amount of heat flowing through the fire-clay part of the side wall is 1.3 times that passing through the fire-clay roof.

Then experiments were made with an air space of 2 inches in the side walls, between 9 inches of fire brick and 8 inches of common and repressed brick, and with a flake asbestos insulation of 1 inch on the roof between 9 inches of fire brick and 4 inches of repressed face brick.

The manner of making and plotting the experiment may be shown by describing the first test of Messrs. Ray and Kreisinger.

Figs. 114, 115, 116 give the temperature drops through the side wall as recorded by sets of couples placed in the side *abd*, and through the roof as recorded by the set of couples placed in the roof *ce* (see Fig. 113). At the bottom of the figure is shown diagrammatically the thickness of the side wall, and at the top of the

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* *Bulletin* 8, Bureau of Mines, 1911.

† The temperature in the furnace was approximately 1000° C.

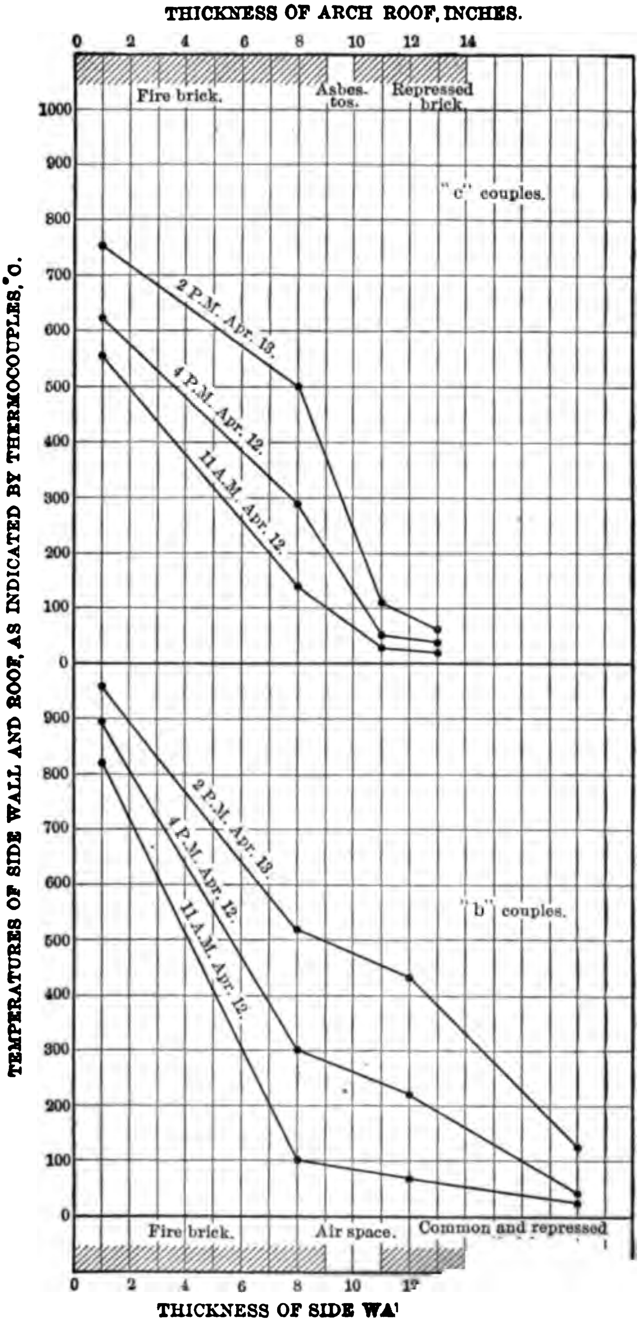
THICKNESS OF ARCH ROOF, INCHES.
0
2
4
6
8
10
12
14
Fire brick.
Asbes-tos.
Repressed brick.
1000
900
800
700
600
500
400
300
200
100
0
"c" couples.
2 P.M. Apr. 13.
4 P.M. Apr. 12.
11 A.M. Apr. 12.
TEMPERATURES OF SIDE WALL AND ROOF, AS INDICATED BY THERMOCOUPLES, °C.
900
800
700
600
500
400
300
200
100
0
"b" couples.
2 P.M. Apr. 13.
4 P.M. Apr. 12.
11 A.M. Apr. 12.
Fire brick.
Air space.
Common and repressed
0
2
4
6
8
10
12
THICKNESS OF SIDE WA

FIG. 114.

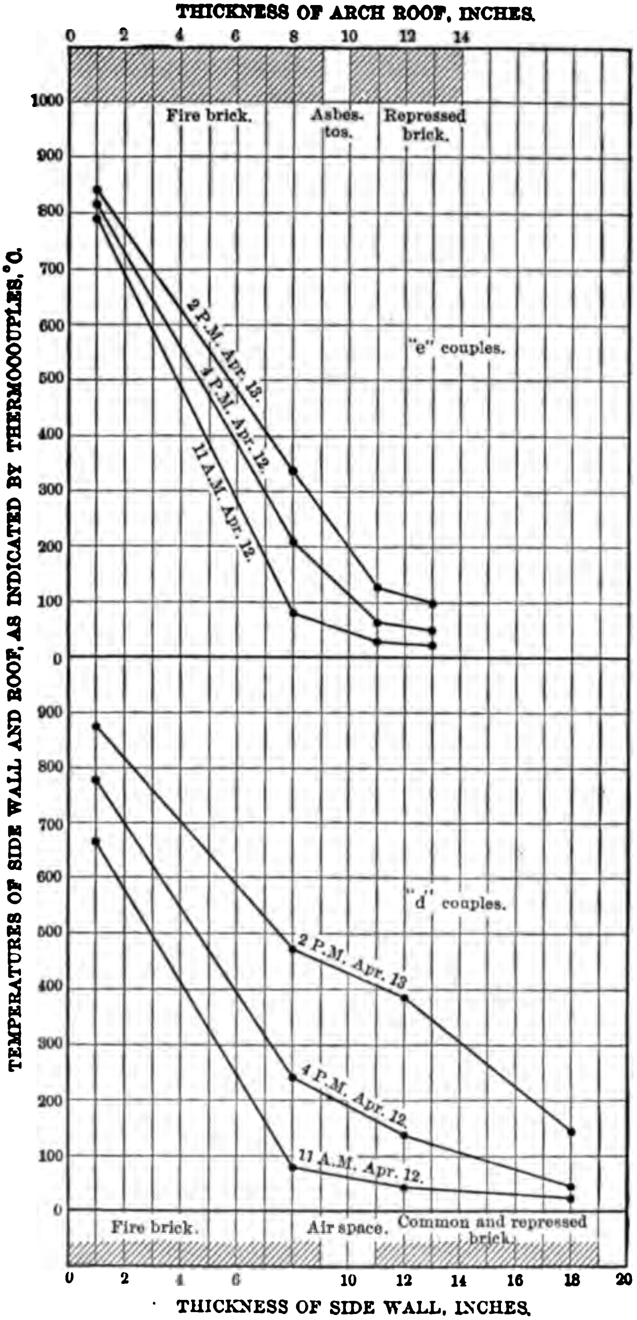
THICKNESS OF ARCH ROOF, INCHES.
0
2
4
6
8
10
12
14
Fire brick.
Asbes-tos.
Repressed brick.
"e" couples.
2 P.M. Apr. 13.
4 P.M. Apr. 12.
11 A.M. Apr. 12.
TEMPERATURES OF SIDE WALL AND ROOF, AS INDICATED BY THERMOCOUPLES, °C.
1000
900
800
700
600
500
400
300
200
100
0
"d" couples.
2 P.M. Apr. 13
4 P.M. Apr. 12
11 A.M. Apr. 12.
Fire brick.
Air space.
Common and repressed brick.
0
2
4
6
10
12
14
16
18
20
THICKNESS OF SIDE WALL, INCHES.

Fig. 115.

figure is shown the thickness of the roof; in each case the measurements of thickness are used as abscissæ in the chart. The temperatures at the various points are plotted as ordinates. The figure shows three temperature gradients or drops through the wall and through the roof, one at 11 A.M., April 12, when the test was started, one at 4 P.M. the same day and one at 2 P.M. the next day.

The first two gradients give the relation of the temperatures before the equilibrium is reached, and are interesting only when

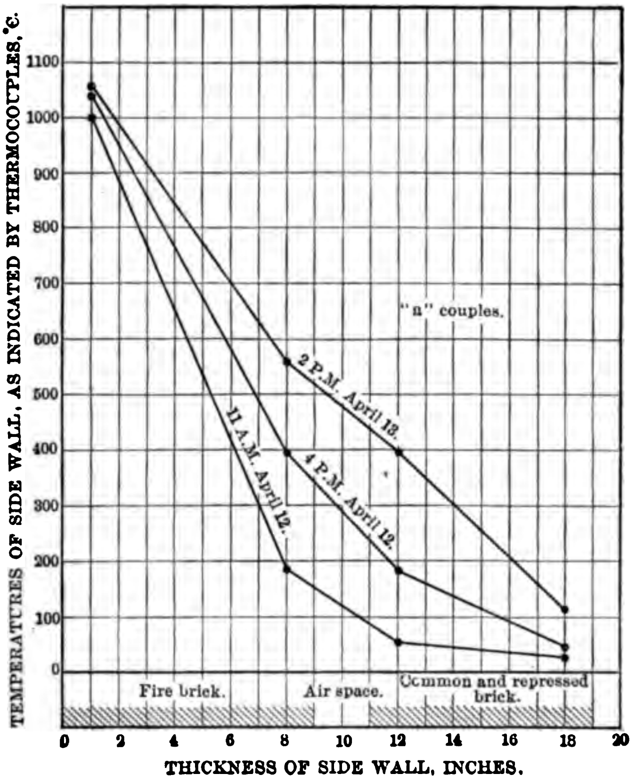

FIG. 116.

compared with one another to show how the temperatures change with respect to each other while the walls are being heated. The last gradient represents the equilibrium and is of most interest.

The striking feature concerning the side-wall thermocouples, set *b*, is the large temperature drop thro wall,
the very small drop through the air

temperature drop through the common brick wall. These drops plainly indicate that the resistance to heat passage of the air space is very low compared with that of either brick wall, being about one-fourth as much. The last temperature gradient through the roof, as given by the set of thermocouples *c*, shows a rather low temperature drop through the fire brick, a high drop through the 1-inch layer of asbestos and a rather small drop through the common brick. These temperature drops indicate that the resistance to heat flow of the 1-inch asbestos layer is higher than that of 7 inches of fire brick. Also, by comparing the last gradient of couples *b* with that of couples *c*, it is easy to see that 1 inch of asbestos is much more effective as a heat insulator under the existing conditions than a 2-inch air space. Although the total thickness of the roof is 5 inches less than that of the side wall, a smaller quantity of heat per square foot is lost through it than through the side wall.

CHAPTER XV

HEAT MEASUREMENTS IN THE METALLURGICAL AND CERAMIC INDUSTRY

ALMOST every engineer and metallurgist wishes to ascertain the temperatures of furnaces, of waste gases, of blast, of slag, matte and of hot metal. Every ceramic engineer must know the temperature at which his ware should be burned.

The progress in the manufacture of exact thermometers and pyrometers has been more active in the last few years than in any previous decade. The later editions of Percy and the earlier books of Kerl are replete with methods of reading high temperatures by the use of the known temperature of fusion of alloys and metals. Later, for high temperatures, mixtures of feldspar with clay or gypsum were used, which led to the introduction by Seger of his well-known scale. The metal scale, still used to a limited extent in Germany, consists of thin metal sheets of the following composition and temperature of fusion:

		Melting at
(1)	800 parts silver, 200 parts copper	850° C.
(2)	950 parts silver, 50 parts copper	900°
(3)	Pure silver	954°
(4)	400 parts silver, 600 parts gold	1020°
(5)	Pure gold	1074°
(6)	950 parts gold, 50 parts platinum	1100°
(7)	900 parts gold and 100 parts platinum	1130°
(8)	850 parts gold, 150 parts platinum	1160°
(9)	800 parts gold, 200 parts platinum	1190°
(10)	750 parts gold, 250 parts platinum	1220°
(11)	700 parts gold, 300 parts platinum	1255°
(12)	600 parts gold, 400 parts platinum	1320°
(13)	500 parts gold, 500 parts platinum	1385°
(14)	Platinum	1775°

The disadvantage of this metal scale lies in the slow fusion of the platinum alloys. The original scale of feldspar mixtures was succeeded by the Seger scale, in which various mixtures of quartz, feldspar and marble alkalis and pure clays form a fairly accurate scale with differences of from 20 to 30° C. between the fusion points of the different mixtures. The clays or clay mixtures are sold in the form of small pyramids and numbered in such a manner that No. 1 melts at 1150° C. while the scale runs down to No. .022, which melts at 590° C., and up to 42, which melts at 1970° C. The composition of the cone which melts at 970°, for instance, which is called No. .09, is as follows: 3.55 part SiO_2, 0.55 part B_2O_3, 0.3 part Al_2O_3, 0.2 part Fe_2O_3, 0.3 part K_2O, 0.7 part CaO. A mixture melting at 1690°, called No. 28, is composed of Al_2O_3, 10 SiO_2.

To determine the temperature of a kiln or furnace it is necessary to use at least three cones. If we know, for example, that the approximate temperature of a vessel is 1500°, we would place on a brick in the kiln, or on a suitable support in the furnace, cones Nos. 17, 18 and 19, which fuse at 1470°, 1490° and 1510° C. Supposing cone 19 did not fuse at all, cone 18 "sweated" and cone 17 turned down, we would know that the temperature of the vessel was between 1470 and 1490° C. The cones find their greatest application in the ceramic industries, and are used almost invariably by makers of high-grade refractories. For further information on the development and on the use of the scale readers are referred to "The Collected Writings of Seger," to the files of that excellent journal "Die Thonindustrie Zeitung" and to the papers of Dr. Orton of Columbus, the *doyen* of American clay workers. The cone should not be regarded as an exact measure of the degree

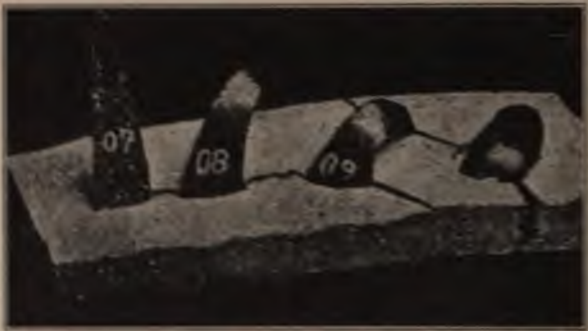

FIG. 117. — Manner of using Seger Cones to determine the Quantity of Heat in a Furnace. In the Illustration Cone 07, which turns over at 1010° C., has not yet fused. Accordingly the Temperature may be set at 1000° C. for Clay Work.

of temperature. It represents to the clay and brick worker the conditions of time and heat which will accomplish certain results in fusion and vitrification. The cone which "turns down" or fuses shows that the stage of heat energy has been reached in the kiln corresponding to the number of the cone which is sometimes broadly translated in degrees of temperature.

Cone number.	Chemical composition.			Temperature of softening.	
				°C.	°F.
022	0.5 Na_2O 0.5 PbO	....	2 SiO_2 1 B_2O_3	590	1094
021	0.5 Na_2O 0.5 PbO	0.1 Al_2O_3	2.2 SiO_2 1 B_2O_3	620	1148
020	0.5 Na_2O 0.5 PbO	0.2 Al_2O_3	2.4 SiO_2 1 B_2O_3	650	1202
019	0.5 Na_2O 0.5 PbO	0.3 Al_2O_3	2.6 SiO_2 1 B_2O_3	680	1256
018	0.5 Na_2O 0.5 PbO	0.4 Al_2O_3	2.8 SiO_2 1 B_2O_3	710	1310
017	0.5 Na_2O 0.5 PbO	0.5 Al_2O_3	3 SiO_2 1 B_2O_3	740	1364
016	0.5 Na_2O 0.5 PbO	0.55 Al_2O_3	3 SiO_2 1 B_2O_3	770	1418
015	0.5 Na_2O 0.5 PbO	0.6 Al_2O_3	3.2 SiO_2 1 B_2O_3	800	1472
014	0.5 Na_2O 0.5 PbO	0.65 Al_2O_3	3.3 SiO_2 1 B_2O_3	830	1526
013	0.5 Na_2O 0.5 PbO	0.7 Al_2O_3	3.4 SiO_2 1 B_2O_3	860	1580
012	0.5 Na_2O 0.5 PbO	0.75 Al_2O_3	3.5 SiO_2 1 B_2O_3	890	1634
011	0.5 Na_2O 0.5 PbO	0.8 Al_2O_3	3.6 SiO_2 1 B_2O_3	920	1688
010	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.50 SiO_2 0.45 B_2O_3	950	1742
09	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.55 SiO_2 0.50 B_2O_3	970	1778
08	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.60 SiO_2 0.40 B_2O_3	990	1814

scale with differences of from 20 to 30° C. between the fusion points of the different mixtures. The clays or clay mixtures are sold in the form of small pyramids and numbered in such a manner that No. 1 melts at 1150° C. while the scale runs down to No. .022, which melts at 590° C., and up to 42, which melts at 1970° C. The composition of the cone which melts at 970°, for instance, which is called No. .09, is as follows: 3.55 part SiO_2, 0.55 part B_2O_3, 0.3 part Al_2O_3, 0.2 part Fe_2O_3, 0.3 part K_2O, 0.7 part CaO. A mixture melting at 1690°, called No. 28, is composed of Al_2O_3, 10 SiO_2.

To determine the temperature of a kiln or furnace it is necessary to use at least three cones. If we know, for example, that the approximate temperature of a vessel is 1500°, we would place on a brick in the kiln, or on a suitable support in the furnace, cones Nos. 17, 18 and 19, which fuse at 1470°, 1490° and 1510° C. Supposing cone 19 did not fuse at all, cone 18 "sweated" and cone 17 turned down, we would know that the temperature of the vessel was between 1470 and 1490° C. The cones find their greatest application in the ceramic industries, and are used almost invariably by makers of high-grade refractories. For further information on the development and on the use of the scale readers are referred to "The Collected Writings of Seger," to the files of that excellent journal "Die Thonindustrie Zeitung" and to the papers of Dr. Orton of Columbus, the *doyen* of American clay workers. The cone should not be regarded as an exact measure of the degree

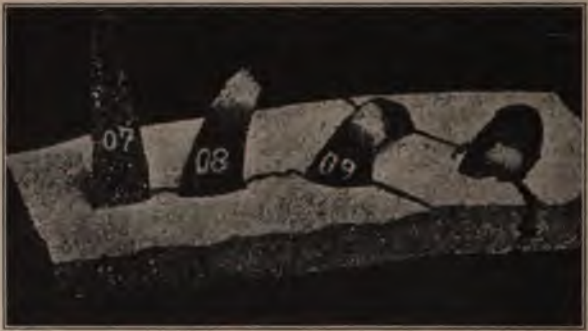

FIG. 117. — Manner of using Seger Cones to determine the Quantity of Heat in a Furnace. In the Illustration Cone 07, which turns over at 1010° C., has not yet fused. Accordingly the Temperature may be set at 1000° C. for Clay Work.

of temperature. It represents to the clay and brick worker the conditions of time and heat which will accomplish certain results in fusion and vitrification. The cone which "turns down" or fuses shows that the stage of heat energy has been reached in the kiln corresponding to the number of the cone which is sometimes broadly translated in degrees of temperature.

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				°C.	°F.
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020	0.5 Na_2O 0.5 PbO	0.2 Al_2O_3	2.4 SiO_2 1 B_2O_3	650	1202
019	0.5 Na_2O 0.5 PbO	0.3 Al_2O_3	2.6 SiO_2 1 B_2O_3	680	1256
018	0.5 Na_2O 0.5 PbO	0.4 Al_2O_3	2.8 SiO_2 1 B_2O_3	710	1310
017	0.5 Na_2O 0.5 PbO	0.5 Al_2O_3	3 SiO_2 1 B_2O_3	740	1364
016	0.5 Na_2O 0.5 PbO	0.55 Al_2O_3	3 SiO_2 1 B_2O_3	770	1418
015	0.5 Na_2O 0.5 PbO	0.6 Al_2O_3	3.2 SiO_2 1 B_2O_3	800	1472
014	0.5 Na_2O 0.5 PbO	0.65 Al_2O_3	3.3 SiO_2 1 B_2O_3	830	1526
013	0.5 Na_2O 0.5 PbO	0.7 Al_2O_3	3.4 SiO_2 1 B_2O_3	860	1580
012	0.5 Na_2O 0.5 PbO	0.75 Al_2O_3	3.5 SiO_2 1 B_2O_3	890	1634
011	0.5 Na_2O 0.5 PbO	0.8 Al_2O_3	3.6 SiO_2 1 B_2O_3	920	1688
010	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.50 SiO_2 0.50 B_2O_3	950	1742
09	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.55 SiO_2 0.45 B_2O_3	970	1778
08	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.60 SiO_2 0.40 B_2O_3	990	1814

Cone number.	Chemical composition.			Temperature of softening.	
				°C.	°F.
07	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.65 SiO_2 0.35 B_2O_3	1010	1850
06	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.70 SiO_2 0.30 B_2O_3	1030	1886
05	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.75 SiO_2 0.25 B_2O_3	1050	1922
04	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.80 SiO_2 0.20 B_2O_3	1070	1958
03	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.85 SiO_2 0.15 B_2O_3	1090	1994
02	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.90 SiO_2 0.10 B_2O_3	1110	2030
01	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.95 SiO_2 0.05 B_2O_3	1130	2066
1	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	4 SiO_2	1150	2102
2	0.3 K_2O 0.7 CaO	0.1 Fe_2O_3 0.4 Al_2O_3	4 SiO_2	1170	2138
3	0.3 K_2O 0.7 CaO	0.05 Fe_2O_3 0.45 Al_2O_3	4 SiO_2	1190	2174
4	0.3 K_2O 0.7 CaO	0.5 Al_2O_3	4 SiO_2	1210	2210
5	0.3 K_2O 0.7 CaO	0.5 Al_2O_3	5 SiO_2	1230	2246
6	0.3 K_2O 0.7 CaO	0.6 Al_2O_3	6 SiO_2	1250	2282
7	0.3 K_2O 0.7 CaO	0.7 Al_2O_3	7 SiO_2	1270	2318
8	0.3 K_2O 0.7 CaO	0.8 Al_2O_3	8 SiO_2	1290	2354
9	0.3 K_2O 0.7 CaO	0.9 Al_2O_3	9 SiO_2	1310	2390
10	0.3 K_2O 0.7 CaO	1.0 Al_2O_3	10 SiO_2	1330	2426
11	0.3 K_2O 0.7 CaO	1.2 Al_2O_3	12 SiO_2	1350	2462
12	0.3 K_2O 0.7 CaO	1.4 Al_2O_3	14 SiO_2	1370	2498
13	0.3 K_2O 0.7 CaO	1.6 Al_2O_3	16 SiO_2	1390	2534

Cone number.	Chemical composition.			Temperature of softening	
				°C.	°F.
14	0.3 K_2O 0.7 CaO	1.8 Al_2O_3	18 SiO_2	1410	2570
15	0.3 K_2O 0.7 CaO	2.1 Al_2O_3	21 SiO_2	1430	2606
16	0.3 K_2O 0.7 CaO	2.4 Al_2O_3	24 SiO_2	1450	2642
17	0.3 K_2O 0.7 CaO	2.7 Al_2O_3	27 SiO_2	1470	2678
18	0.3 K_2O 0.7 CaO	3.1 Al_2O_3	31 SiO_2	1490	2714
19	0.3 K_2O 0.7 CaO	3.5 Al_2O_3	35 SiO_2	1510	2750
20	0.3 K_2O 0.7 CaO	3.9 Al_2O_3	39 SiO_2	1530	2786
21	0.3 K_2O 0.7 CaO	4.4 Al_2O_3	44 SiO_2	1550	2822
22	0.3 K_2O 0.7 CaO	4.9 Al_2O_3	49 SiO_2	1570	2858
23	0.3 K_2O 0.7 CaO	5.4 Al_2O_3	54 SiO_2	1590	2894
24	0.3 K_2O 0.7 CaO	6.0 Al_2O_3	60 SiO_2	1610	2930
25	0.3 K_2O 0.7 CaO	6.6 Al_2O_3	66 SiO_2	1630	2966
26*	0.3 K_2O 0.7 CaO	7.2 Al_2O_3	72 SiO_2	1650	3002
27	0.3 K_2O 0.7 CaO	20 Al_2O_3	200 SiO_2	1670	3038
28	....	Al_2O_3	10 SiO_2	1690	3074
29	....	Al_2O_3	8 SiO_2	1710	3110
30	....	Al_2O_3	6 SiO_2	1730	3146
31	....	Al_2O_3	5 SiO_2	1750	3182
32	....	Al_2O_3	4 SiO_2	1770	3218
33	....	Al_2O_3	3 SiO_2	1790	3254
34	....	Al_2O_3	2.5 SiO_2	1810	3290
35	....	Al_2O_3	2 SiO_2*	1830	3326
36	....	Al_2O_3	2 SiO_2†	1850	3362
37	....	Al_2O_3	1.66 SiO_2	1870	3398
38	....	Al_2O_3	1.33 SiO_2	1890	3434
39	....	Al_2O_3	1 SiO_2	1910 (1880)	3470
40	....	Al_2O_3	0.66 SiO_2	1930 (1920)	3506
41	....	Al_2O_3	0.33 SiO_2	1950 (1980)	3542
42	....	....			3578

* Kaolin. † C

Since the development of the pyrometers of the thermocouple and radiation type, the exactness of work deduced from the fusing point of Seger cones has been frequently discussed. Dr. Hoffmann * of the Physikalisch-Technischer Reichsanstalt describes his exact researches into the accuracy of the scale in field work. He found in repeated laboratory experiments that the cones fused at approximately the temperatures indicated on the scale, but in the kiln or furnace at very different temperatures. In all cases the cones fused at a temperature of from 45 to 95° C. lower than that indicated on the scale.

Dr. Hoffmann conducted his field work in a silica ware kiln, or a Rundofen belonging to the Rhenish Chamotte and Dinas Works in which chamotte was burned under the ordinary conditions which accompany the manufacture of the refractory ware. Before testing the cones in the kilns he most carefully determined their fusion point in the laboratory, and controlled the results obtained in the Rhenish work by tests in the Royal Porcelain Factory at Berlin.

The appended table shows the results obtained.

No.	1	2	3	4	5	6	7
	Temp. of softening given on the Seger scale.	Temperature read			Average of 3 and 4.	Difference 5, 4 and 2.	
		in the elec. lab. furnace of the Reichsanstalt.	in the Berlin Porcelain Factory.	in the Rhenish ceramic furnaces.			
	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
2	1170	....	....	1125	1125	−45	...
3	1190	....	....	1145	1145	−45	.....
4	1210	1225	....	1160	1160	−50	− 65
5	1230	1225	....	under 1200	....	....	.....
6	1250	1260	....		....	....	.....
7	1270	1285	1180		1180	−90	−105
8	1290	1305	1190	1210	1200	−90	−105
10	1310	1335	1225	1220	1225	−85	−110
13	1390	1395	1315	....	1315	−75	− 80
14	1410	1415	1375	....	1375	−35	− 40
16	1450	1460	....	1395	1395	−55	− 65
17	1470	1480	....	1400	1400	−70	− 80

The cause of the lower temperature of fusion in the porcelain and dinas works is due first of all to the increased length of time in which the cones are exposed to the influence of heat, particularly

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* *Thonindustrie Zeitung*, 1911, p. 1099.

at the temperature near which they would soften and fuse. Another reason probably lies in the chemical effect of the fire gases and dust. We are all familiar with the crust which forms on the sides of the cones most exposed to these gases, which is formed by the disc forming a more readily fusible slag with the clay. Even when the cones are placed in cups, this is not altogether avoided. These conditions do not obtain in the laboratory furnaces.

Dr. Hoffmann has confirmed, by his tests on an iridium laboratory furnace, the scale of fusion temperatures of cones given by Seger and others. The conditions in the laboratory do not obtain in the field and he has demonstrated that the Seger cones do not fuse in the kilns at the temperature indicated both by the scale and the test in the iridium furnace. He recommends the use of the thermocouple pyrometer to determine temperatures in kilns and furnaces. But until we have invented pyrometers which will determine high temperatures with a greater degree of exactness than the present types of thermocouple and optical pyrometers, the cones will maintain their field of usefulness to ceramic workers. They represent heat energy in time and degrees obtained in kilns, rather than the actual temperature existing at the time of observation.

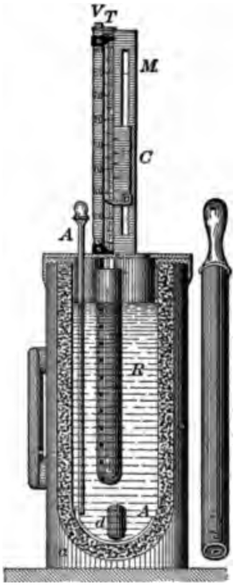

FIG. 118. — Siemens' Water Pyrometer.

Thermometers. — The other methods of determining temperatures are provided by thermometers and pyrometers of the resistance, thermoelectric and optical types, and further (where extreme accuracy is not required) by the ingenious water pyrometer (Fig. 118). Before the development of the first-named types of pyrometers the water pyrometer served a very useful purpose in the wide field of metallurgy. It was simple in construction and easy to manipulate. As the quicksilver thermometer cannot be used for temperatures above 550° C. (even when compressed gases, such as nitrogen, are used in the capilla
bove 350° C. in the ordinary thermometer, the
ployed in

reading temperatures up to 1500° C. The apparatus of a Siemens' water pyrometer consists of a disc of nickel, platinum or copper, a can containing more than a pint of water and a thermometer and scale. The cylinders, or discs, are so adjusted that their heat capacity at ordinary temperatures is equal to one-fiftieth of that of the copper vessel with the pint of water. To measure furnace temperatures it is only necessary to hold the disc in the furnace by a pair of tongs until it has assumed its temperature; then, withdrawing the disc, drop it into the water in the can and mark the rise in temperature which the thermometer records.

A scale is provided at the side of the thermometer scale and shows the temperature. This corresponds to the level of the meniscus of the mercury. This high temperature scale is tested, before the pyrometer leaves the factory, for the actual rise in degrees of the mercury will represent a different value on the high temperature scale for different water contents of the can. Copper discs are used in the reading of temperatures up to 1000° C., nickel, 1400° C. and platinum, 1500° C. Generally, one pint of water is used and the discs weigh respectively 137, 117 and 402 grams. The actual temperature of the furnace will be represented by the addition of the reading on the high temperature scale to the gain in temperature on the thermometer scale caused by the communication of the heat of the disc to the water in the can. The application of the water pyrometer is found more generally in steel works where the temperature of armour plate and steel boxes in the course of finishing will be decided by placing a disc on them and then reading the temperature after dropping the disc into the can.

Self-recording Pyrometers. — The most widely used of the resistance type, employing the principle that heated platinum wire has a different electrical conductivity to the cold metal, is employed for measuring temperatures up to 1200° C. Another principle, that the contact of two metals at a fairly high or high temperature induces an electrical current which may be read on a galvanometer, is applied under the name of the thermoelectric pyrometer in the use of such couples as copper-constantan for temperatures up to 500° C.; platinum-platinum rhodium for temperatures up to almost 1500° C. and platinum-platinum iridium up to 1500° C., while nickel-nickel alloys are employed for the reading of temperatures up to 1000° C. Many other couples are in vogue, such as iron-nickel chrome.

Electric-resistance Pyrometer. — This consists of two essential parts — the heating element and the indicator. The former is a coil of platinum wire wound about two strips of mica and enclosed in a porcelain tube. Under these conditions the resistance of the coil undergoes no change such as would occur if heated in the presence of silica, clay, iron or furnace gases, and may be used for an indefinite number of times with concordant results. The coil of platinum wire, about 1 inch long, is wound on the mica plates, and connected to heavy copper or platinum leads insulated from one another by fire-clay tubes. These leads are connected to binding posts in the handle of the instrument. Compensating leads of the same size as the conducting bands extend from the platinum coil to the binding post, and from the latter the two sets of leads are connected to opposite arms of a Wheatstone bridge. The resistance current on [illegible] g leads and that on the

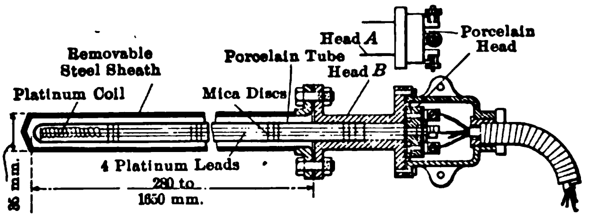

Fig. 119. — Platinum Electric-resistance Pyrometer.

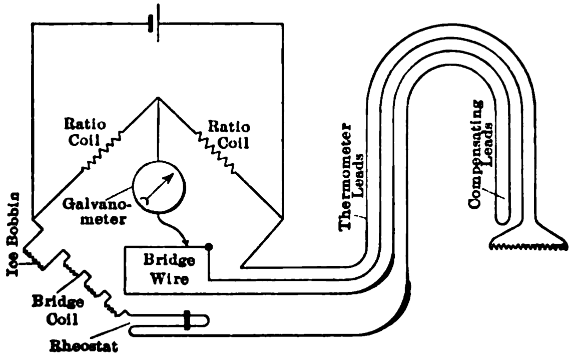

Fig. 120. — Electric-resistance Pyrometer.

compensating leads balance each other so that the change in resistance to current measured on the Wheatstone bridge, when the platinum coil is exposed to the heat which is to be determined, is due solely to the change in the platinum resistance coil, which varies with the degree of temperature. The electric-resistance pyrometer may be used both for temperatures below zero as well as for temperatures up to 1200° C., when platinum begins to volatilize and the resistance is increased. The temperature may be read on a galvanometer which is graduated in Fahrenheit or centigrade degrees, or by the use of a telephone and a pointer which is slid along a resistance-cable wire and is held when the humming in the telephone stops. The number of degrees which the pointer now indicates represents the temperature of the hot body in which the platinum coil is inserted.

The thermoelectric pyrometer is capable of measuring temperatures approaching the melting point of platinum by means of the current produced by the heating of the junction of a thermoelectric couple registering on a D'Arsonval galvanometer. For general purposes one of the wires which compose the couple is of platinum alloyed with 10 per cent rhodium, while the other is of pure platinum. The couple protected by a tube of fire clay and connected with the galvanometer is inserted in the furnace or oven when a current is produced and measured on the galvanometer scale, which is calibrated in millivolts and degrees. The thermoelectric pyrometer is almost instantaneous in its indications of the temperature; a reading may be made in five seconds after insertion in the heated body, or, if desired, it may be left permanently in the furnace and the temperature may be written on an automatic scale recorder. It is generally adopted for high temperatures (between 1000 and 1600° C.).

Optical Pyrometers. — Where contact with a hot body, gas or flame is difficult the temperature may be read under normal conditions with fair accuracy by means of an optical pyrometer. The types of optical pyrometers in more general use are the Fery radiation, the Fery absorption and the Wanner pyrometer. The Fery radiation pyrometer finds its field of usefulness in the range of high temperatures, such as measuring the heat of the flame of a Bessemer converter. Since the pyrometer is always placed at some distance from the furnace and no part of it becomes excessively hot, it is always in good order, and work with it is both rapid and comfortable. The principle of the radiation pyrometer is this: the radiation which emanates from a hot body or which passes out through an observation hole in the wall of the furnace, falls upon a concave mirror and is thus brought to a focus. In this focus is a thermoelectric couple, the temperature of which is raised by the radiation falling upon it. This is connected with a galvanometer recording, in millivolts and degrees, the temperature. The hotter the furnace, the greater the rise of temperature of the couple. The arrangement of the pyrometer precludes any influences that would impair accuracy from the size of the hot body or observation hole, and also from the distance of the pyrometer from the hot body or furnace. Thus the temperature of a stream of molten steel was found to measure the same at a distance of 3 feet and also of 60 feet from the pyrometer. The instrument may be used continuously and be connected to a self-recording heat register.

For measuring the temperature of such small hot bodies, as incandescent filaments, the Fery absorption pyrometer has found a widening field of application. It consists of a small telescope which carries a small lamp called the comparison lamp. The image of the flame of this lamp E, Fig. 121, is projected on a mirror

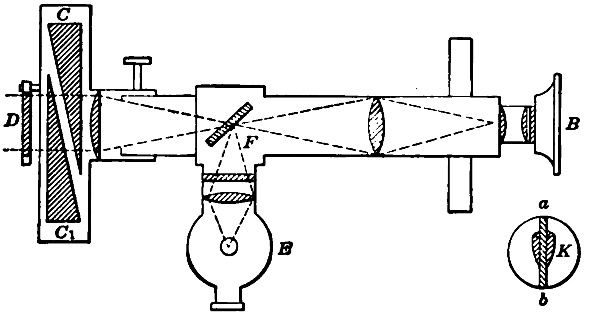

FIG. 121. — Fery Absorption Pyrometer.

F at 45°, placed at the principal focus of the telescope. A narrow vertical strip $\alpha\beta$ of this mirror F is silvered. The telescope is focused on the object, which is viewed on either side of the silvered strip. By means of a pair of absorbing-glass wedges C and C_1, which are moved laterally by a microme ’om the object is made photometrically equ •

son lamp. An auxiliary dark glass D enables the instrument to work over a higher range of temperature. A table converts the readings obtained by the scale and micrometer into degrees centigrade. In the figure K represents a crucible on which the telescope is focused.

The Wanner is an optical absorption pyrometer which can measure temperature from 625 to 1000° C. The use of it involves the comparison of the quantity of light emanating from the heated mass to be measured with a constant source of light.

In order to be able to measure low temperatures and minimize loss of light in passing through the apparatus, a small two-volt osmium lamp, placed within the vertical handle which joins the horizontal optical tube, is used as the standard light. A battery of cells provides current for the osmium lamp, which may be standardized and controlled by an accessory amyl-acetate lamp with either a support for adjustment, which indicates the normal condition on a scale, or by a resistance box, which is switched into the lamp circuit along with a voltmeter.

In adjusting the pyrometer the amyl-acetate lamp is placed at the opposite end of the pyrometer to the eyepiece. This lamp is provided with sights which are placed in a line with the pyrometer. Then the osmium lamp is connected with the battery. Now on looking through the eyepiece and pressing the button of the handle, a red illuminated circle becomes visible; the upper semicircle is lighted by the amyl acetate, the lower by the osmium incandescent lamp. When the two semicircles are equally bright, the pyrometer is ready for use. To measure the temperature of a furnace remove the amyl-acetate lamp used for standardizing and point the photometer toward the door or source of heat, make comparisons of the illuminated semicircles and adjust to equal fields. By means of the figure or number obtained from the scale of adjustment on the pyrometer the temperature is read from a table.

To adjust the pyrometer fitted with voltmeter, light the amyl-acetate lamp as before, adjusting it to normal conditions, and correct the pyrometer-osmium lamp to equally illuminated fields. The voltage on the meter is that at which the osmium lamp is now burning. The voltage of a new osmium lamp is given by the manufacturers.

Pyroscope. — Among the very useful pyrometers must be classed the pyroscope, made by The Shore Instrument and Manufacturing

Company. This is marketed in two classes. The first reads temperatures from 1200 to 2000° F., and the second, temperatures from 2000 to 3000° F. It is an optical pyrometer in which the comparison of the intensity of light in a furnace, or emitted by an object, is made with an ordinary kerosene lamp. It is accurate to within 20° F. and is always in fair order and may be turned over to furnace men to use in case-hardening, ceramic and other work.

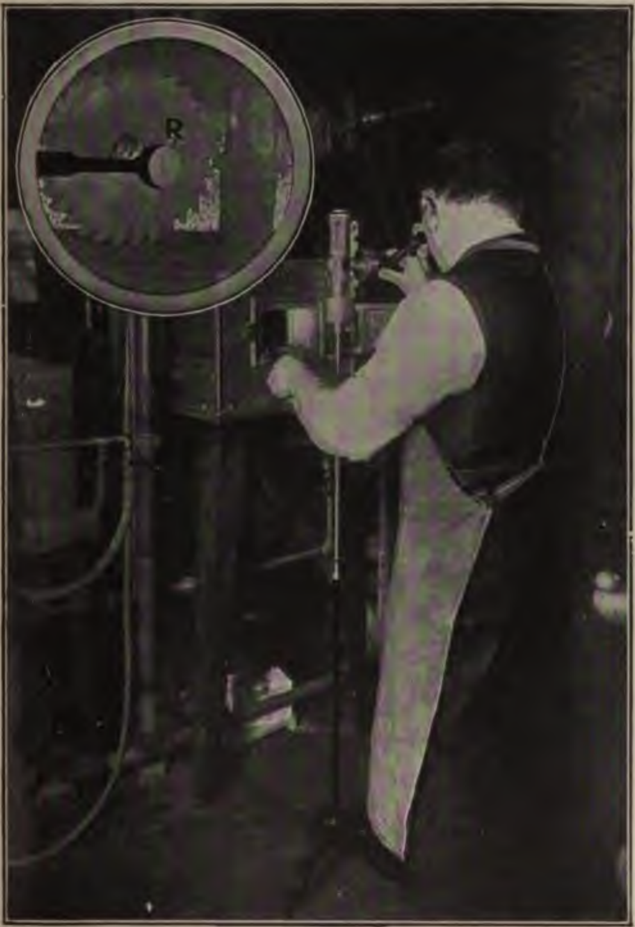

FIG. 122. — The Shore Pyroscope.

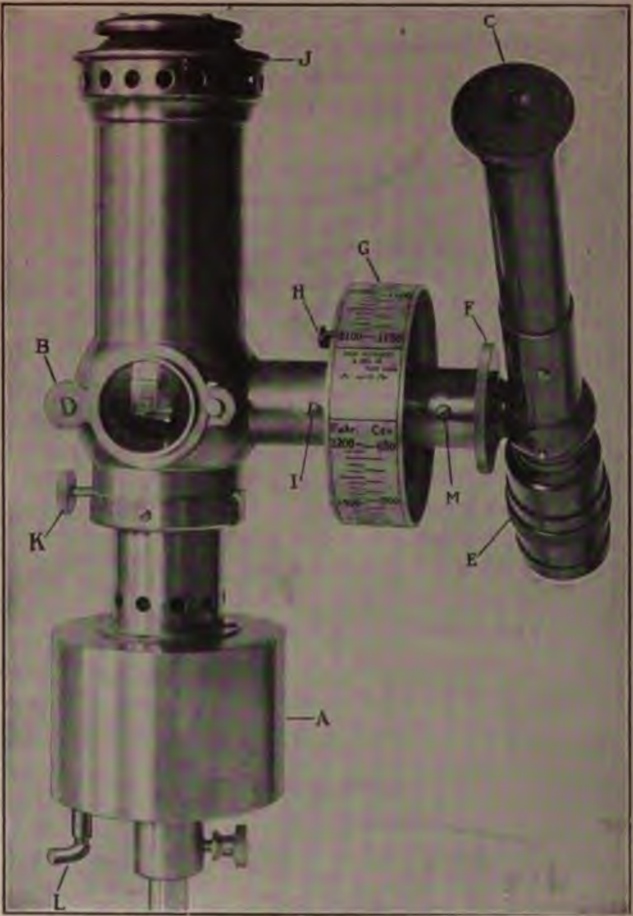

FIG. 123. — The Shore Pyroscope.

Calculation of Temperatures. — When no pyrometer is at hand temperatures may be relatively calculated from these data, the weight of the fuel used, its calorific value, the weight of the products of combustion and their specific heat. For instance, the temperature produced by 1 kg. of carbon of the calorific value 2473 and producing 2.33 kg. of CO and 4.46 kg. of N (after absorbing O for combustion) would be found thus:

$$T \text{ (temp.)} = \frac{W \text{ (cal. val. of fuel)}}{Q \text{ (product of combustion)} \times S \text{ (their specific heat)}},$$

or, in the case above

$$= \frac{1 \text{ kg.} \times 2473}{2.33 \times 0.248 + 4.46 \times 0.244} = 1486^\circ \text{ C.},$$

where 0.248 and 0.244 represent the specific heat of CO and N respectively.

Since, however, carbon and oxygen do not combine at 0° C., we must add the heat already provided to effect their combination. For instance, suppose the carbon heated by the gases rising in the shaft of a furnace. Let us assume that the temperature of these gases is 1200° C. Then 1 kg. of carbon will, in addition, furnish the extra calorific power obtained from being heated to 1200°, which amounts to 1200 × 0.22 (the specific heat of carbon) or 264 cals. Then the real heat produced by the combustion of 1 kg. of carbon will be

$$= \frac{2473 + 264}{2.33 \times 0.248} + 4.46 \times 0.244 \text{ or } 1659^\circ \text{ C.}$$

Should the air or blast be heated to say 400° C., we have a further increase of heat value and raising of temperature by the following amount. The quantity of air used to burn 1 kg. C is 5.79 kgs.; its specific heat is 0.237, its temperature 400° C.

$$5.79 \times 0.237 \times 400^\circ = 548,$$

therefore,

$$T = \frac{2473 + 264 + 548}{2.33 \times 0.248} + 4.46 \times 0.244 = 1973^\circ \text{ C.}$$

Similarly, if the temperature be known, the total heat energy may be calculated:

$$W = T(QS + Q_2S_2 + \cdots)$$

where Q = the products of combustion.

The temperature indicated by the preceding calculations will be diminished by the loss of heat, such as is demanded for warming the walls of the furnace, for radiation and for effecting chemical dissolution of compounds.

Yet the rule stands, that every increase of the products of combustion without corresponding increase of the heat energy reduces the temperature of combustion. Nitrogen and moisture in air are accordingly dead weights. Moisture is
mental to high temperatures on account of i

Accordingly, the less moisture and the less nitrogen we have in blast for combustion, the greater the temperature we produce. We cannot control the nitrogen, but we can very often eliminate the moisture. The appended calculations show the relative value of producer gas with and without moisture.

The gas in question analyzed 17.4 per cent moisture and $CO_2 =$ 11.8 per cent by volume.

Constituents.	Percentage by volume.	Percentage by weight without moisture.	Percentage by weight with moisture.
		19.42	16.10
CO	13.4	14.02	11.59
CH_4	3.0	1.68	1.39
H	10.5	0.79	0.66
N	61.3	64.09	53.02
			17.24
	100	100	100

Let T' represent the temperature produced with moisture content, and T'' represent the temperature produced without moisture content, by 1 kg. gas.

$$T = \frac{\text{wt. CO} \times \text{cal. value} + \text{wt. CH}_4 \times \text{cal. value} + \text{wt. H} \times \text{cal. value}}{\text{wt. CO}_2 \times \text{spec. heat} + \text{H}_2\text{O} \times \text{spec. heat} + \text{N} \times \text{spec. heat}}.$$

$$T' = \frac{0.1402 \times 2403 + 0.168 \times 1200 + 0.0079 \times 28780}{507 \times 0.217 + 0.109 \times 0.480 + 1.835 + 0.244} = 1255^\circ \text{ C.}$$

$$T'' = \frac{0.1159 \times 2403 + 0.0139 \times 1200 + 0.0066 \times 28780}{0.419 \times 0.217 + 0.263 \times 0.480 + (1.517 \times 0.244)} = 1082^\circ \text{ C.}$$

Had regenerative checkers been used in the furnace in which the gases were burned, the calculations would be modified. To the calorific value as obtained above would be added the heat energy produced from the quantity of gases passing through the checkers. This, multiplied by the specific heat and then by the temperature of the checkers, say, 400° C., represents the heat energy.

$$\text{Then} \qquad T = \frac{765.382 + 400 \times 0.24}{0.61} = 1411^\circ \text{ C.}$$

$$\text{and} \qquad T'' = \frac{635.496 + 400 \times 0.28}{0.587} = 1273^\circ \text{ C.}$$

The difference in the specific heats of the gases calculated under T' and T'', namely 0.61 and 0.587, is due to the content of moisture in the gas with a value of 0.587.

Note that the CO_2 and H_2O result as follows:

CO_2	In gas without moisture.	In gas with moisture.
	kg.	kg.
CO_2 itself	0.194	0.161
CO_2 from combustion of CO	0.220	0.182
CO_2 from combustion of CH_4	0.093	0.076
	0.507	0.419
H_2O	In gas with moisture.	In gas without moisture.
	kg.	kg.
H_2O from CH_4	0.038	0.032
H_2O from H	0.071	0.059
Moisture	0.0	0.172
	0.109	0.263
N	Without moisture.	With moisture.
	kg.	kg.
N itself	0.641	0.530
N drawn in with O in air which forms CO_2+H_2O with CO+H	1.194	0.937
	1.835	1.517

CHAPTER XVI

THE PREPARATION AND USE OF THE COMMON KINDS OF BRICK

COMMON brick may be divided into the two general classes of clay and sand-lime brick. The clay brick varies in character and composition from that of the sun-burned adobe mud form, made in large quantities in hot dry countries, to the first-class face, paving and fire brick.

The sand-lime brick is not as strong as the better class of clay brick. Yet it is being used for the inside and faces of building walls and has been laid in the form of paving blocks in Europe.

The preparation of clay brick may be considered in the processes of mining, cleaning and grinding the clay and of moulding, drying and burning the brick.

The Deposit.* — When a deposit of clay has been found and proved to be of such a quality as to warrant further testing, the shape and extent of the deposit should be determined as accurately as possible. Then, a knowledge of its texture and uniformity must be obtained, i.e., whether the clay contains sand, gravel, concretions, etc. If these occur in streaks they may be avoided in mining. The character and thickness of the overburden is an important factor to be considered, for it influences largely the method and cost of extraction. If the clay bed is not exposed across its entire thickness, holes should be bored through it at several points and the borings carefully preserved for samples. A post-hole auger, cutting a hole 3 or 4 inches in diameter, will be found to be convenient for this purpose up to depths 30 to 40 feet. The size of the samples to be taken will depend upon the locality and convenience of transportation. When it is possible, 50-pound samples should be sacked so as to insure plenty of material for a test on a working scale to supplement the laboratory tests. If it is not practicable to get samples of this size, 5- or 10-pound samples should be taken as a minimum. The samples should be taken from several points on the clay bed and from the bore holes. If larger samples are desired for running large working tests, pits should be dug at the points where the borings were made. Clays are usually wet and sticky and for that reason any ordinary tag or label would be destroyed or the mark obliterated. Experience has shown that the best system of labelling clay samples is to use small tin discs upon which the mark is stencilled.

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* In this chapter I have used extensively an article by Edgar K. Soper, in *Eng. & Min. Journal*, Feb. 3, 1912.

Testing the Clays. — While almost any clay may be used for making common brick, many clays are especially suited to some particular use, depending upon their characteristic properties and also to a large extent upon the situation and prevailing industry of the region. This particular use is the one to which the clay should be put in order to insure the largest profit, so the problem at hand, after the discovery and location of a deposit, is to determine the use for which the material is best adapted. A chemical analysis of a clay is of little practical value, except in a few cases to be mentioned later. The commercial value of most clays will only be disclosed after a careful consideration of their physical properties. The most important tests to make are the following: (1) water required to attain maximum plasticity; (2) the air shrinkage; (3) fire shrinkage; (4) percentage of absorption after burning at different temperatures; (5) color after burning at different temperatures; (6) fusibility; (7) tensile strength; (8) plasticity; (9) rapid drying test.

A mechanical test is often desirable to determine the relative amounts of the different sizes of the constituent grains. If the clay is to be subjected to artificial rapid drying, it should be tested to see whether it will stand it without warping or cracking. A simple chemical test often made is the determination of soluble salts. In clays to be used in the manufacture of Portland cement the percentage of $CaCO_3$ and dolomite is important. All of the physical tests enumerated above are made in the laboratory on small bricklets about 4 by 1 by $\frac{3}{4}$ inches. The question as to how these laboratory results will compare with those obtained in actual practice is one which is commonly raised. In general, if the tests are carefully conducted, the results will be close. The air shrinkage is sometimes higher than in the factory on account of better mixing facilities at the latter place. In very sandy clays the error will be the other way. In practice the kilns are fired slowly than in the laboratory and this generally results in brighter colors at the factory since the iron in the clay has a better chance to oxidize.

Mining Methods. — Clays and shales are commonly worked as open pits or quarries, but in some instances underground methods are employed. If the deposit lies near the surface and but little overburden must be removed, then open quarries are universally employed. Clays are usually soft and do not require the use of explosives. In small operations where only a limited amount of clay is mined hand labor with pick and shovel is commonly used, but in more extensive plants, plows and scrapers, or even steam shovels are in use. In some deposits of tough clay or hard shale, blasting is frequently necessary in order to loosen the material. Clay pits are usually drained by a series of ditches.

If the clay bank is high (over 75 feet) it is usually carried down in a series of steps or terraces in order to prevent sliding when the clay becomes saturated with water, especially after a heavy rain. This slipping or sliding along some seam or contact zone in the clay is a danger constantly present in high banks of wet clay, and the factory or structure of any kind should never be placed at the base of such a bank. In several instances entire clay yards have become buried beneath one of these landslides.

Where the clay is not uniform, but contains alternate layers of material of variable composition, it is often desirable to excavate these different grades by layers and store them in separate piles. Another method of mining deposits of mixed clays is by a series of small pits dug by hand with a gouge spade. The material is graded and thrown into separate heaps at the surface. Where the pit is too deep for the workmen to throw the clay to the rim a platform is constructed half way to the surface, and the material is shovelled from the platform to the top of the pit. Buckets and windlasses are also used.

The method of haulage from the bank to the shipping point or works will depend chiefly on the distance and quantity of material to be hauled, and also upon the topographic conditions. If the works are near at hand, the clay is trammed by hand or in barrows from the pit. Mules are often used to haul a train of six or eight cars, or horses and carts may be employed. Where the pit is roughly circular, in plan, and carried down in a series of steps or terraces, horses and carts are convenient and can be placed at the bank and the clay can be broken directly into the carts. In regions of a precipitous character, or where the works are placed at elevations considerably above or below the clay pit, aërial tramways are often employed. Steam haulage is used only in the larger works, and in general is economical only for distances greater than 1000 feet, and where the locomotive is kept more or less constantly employed. Various methods of stripping the clay beds are in use in different localities. Where the overburden is thick and extends over the entire deposit, steam shovels may be profitably employed. Wheel scrapers are often used where the distance to the dump is short. Some large clay beds have been stripped by hydraulic methods.

Kaolin Mining. — Since most of the kaolin deposits worked in the United States are long and narrow, a method often adopted consists in sinking a circular pit in the kaolin about 25 feet in diameter. As the pit proceeds in depth it is lined with a cribwork of wood. This lining is extended to the full depth of the pit which varies from 50 to 100 feet. When the bottom of the good clay is reached, the filling in of the pit is begun, and the cribwork is removed from the bottom and the timber recovered. Another pit is then started, adjoining the first one. Often several pits are carried down together. In the Cornwall district of England a somewhat unusual method is employed for mining a sandy kaolin at considerable depth. This method is as follows:

A shaft is sunk in the firm rock of the footwall of the deposit, which occurs as a steeply dipping kaolin vein. The shaft is continued to a depth of about 20 fathoms and from the bottom a crosscut is driven to tap the vein. A raise is then put up through the clay and extended to the surface. In this raise a tight wooden launder is placed, and this is provided with lateral openings about two feet apart, each of which is closed by a temporary wooden cover. This is called a "buttonhole" launder. The shaft is equipped with suitable pumps and work is ready to begin. The clay ground around the top of the launder is loosened to a depth of 6 or 8 feet, and a strong stream of water played on it. The clay becomes disintegrated and the fine clay particles are washed down the launder, through the crosscut to the sump of the shaft, from where the mixture is pumped to the surface. Here the milky mixture of clay and water is conducted through a series of broad shallow troughs. These are set nearly horizontal, and the stream is divided again and again to lessen the rate of flow and allow the fine sandy and micaceous particles to settle. The refined clay stream is finally conducted to vats where the clay substance is settled out, pressed, dried and is then ready for use.

A. R. Ledoux * describes a similar method recently adopted to work the kaolin deposit at West Cornwall, Conn. This deposit is not a sediment, but is a residual deposit in place. The clay lies in steeply-dipping veins, between a footwall of limonite and a hanging wall of gneiss and schist. The scheme of mining is to disintegrate the kaolin in place by jets of water under pressure, and to float the resultant product to the surface. To accomplish this holes are drilled through the overlying gneiss, a pipe of 4-inch internal diameter is inserted in the hole and driven into the clay to within a few feet of the footwall. The wells in operation are from 50 to 198 feet deep. A 2-inch pipe is inserted in the 4-inch one, thus leaving an annular space around the inner pipe for the upward flow of the " slip " (slime). The clay particles are thus brought to the surface by the same general method that drill cuttings are brought up in churn-drill operations.

Underground Methods. — When a clay bed is covered by so great a thickness of overburden as to render open-pit excavation out of the question, underground methods may be adopted if the clay is of high enough grade to make the operations profitable. Such methods, as a rule, are justified only in the case of fire clays or high-grade kaolin. If much water is present it may render the deposit unworkable. The output from such clay mines is usually restricted, unless the workings underlie a large area and can be worked from several shafts or adits. Underground methods in clay deposits are chiefly developed in Maryland, Indiana, Pennsylvania, Missouri and a few other states where fire clays associated with coal seams are mined in this manner.

Preparation for the Market. — Most clays do not require much preparation before they are ready for the plant. Occasionally they are hand picked to rid them of concretions, pyrite balls, etc. Often the clay is spread out in the sun to dry for a few days before being sent to the mixing pit. In the case of high-grade kaolin and china clay, they are often subjected to a washing process to eliminate any sand, pebbles and other impurities. The disintegration of the kaolin is usually accomplished in washing troughs, in which there revolves a shaft, carrying a series of arms or blades which mix the clay thoroughly with water. The water and suspended clay is then discharged into a series of wooden troughs set nearly flat. As the " slip " passes through these troughs the heaviest particles of sand settle first, and lastly the fine clay substance is settled in large settling tanks.

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* *Transactions*, Am. Inst. Min. Eng., 1910.

Methods of Brickmaking. — The commonest clay product, and the most important of all, is brick. The manufacture of brick is such an important industry and one so widely carried on that a brief consideration of the methods in use may not be out of place.

There are three ways of moulding brick. These are: (1) soft-mud process; (2) stiff-mud process; (3) dry-press process. The clay to be moulded, if either of the first two methods be used, must first be ground and then mixed with water to a plastic mass. In the dry-press method the ground clay is pressed dry, without the addition of water.

In the soft-mud process the bricks are moulded in individual moulds, either by hand or by a moulding machine. Most plants in the United States now use machines which commonly mould six bricks at once. The clay is worked up to the consistency of a soft mud or paste and pressed into these wooden moulds. To prevent the sticky clay from adhering to the moulds, sand is added to the sides of the moulds before ramming in the clay. Soft-mud bricks, therefore, usually show five sanded surfaces, which distinguish them from bricks moulded by the other processes. The soft-mud process of moulding is adapted to a wider range of clays than any other method, for obviously any clay that is plastic may be worked up by adding the proper amount of water.

In the stiff-mud process the ground clay is mixed with less water than in the former case, and to the consistency of a stiff mass of sufficient plasticity to be moulded to shape and yet retain its shape while still wet. The plastic mass is fed into a long cylindrical drum which tapers to a small end in which there is a rectangular opening or die, the desired size of the bricks. The clay is forced toward this small end by a revolving screw, and is finally squeezed through the die from whence it emerges in the form of a long continuous bar of rectangular section. This b
received on a moving table which carries it past a row of
or wires operating on a lever which is lowered at proper

and cuts the bar of clay into bricks. The capacity of a stiff-mud machine is from 45,000 to 60,000 bricks per 10 hours, as compared with 40,000 by the soft-mud method. The stiff-mud process is not adapted to so wide a range of clays, however, for only clays of medium plasticity are used.

In the dry-press process the clay is powdered and then pressed into steel moulds in a dry or semi-dry condition. The faces of the moulds are of hard steel and are heated by steam to prevent the clay from adhering to them when pressed. They are also provided with air holes to allow the air to escape during pressing, for if the air were imprisoned with the clay, when the pressure is removed the air would expand and split the brick. The dry-press process is used extensively in the manufacture of front or facing brick, for in one operation a brick is produced with sharp edges and smooth surfaces. If six bricks are moulded at a time, the dry-press machines have a capacity equal to that of the soft-mud machines.

Drying. — Before bricks from the soft- or stiff-mud processes can be burned they must be dried to free them from most of their water. This drying is done (1) in open yards; (2) in pallet driers placed indoors or in sheds; or (3) in drying tunnels. The advantage of the latter method is that drying may continue without interruption throughout the year. Several tunnels or chambers are constructed side by side, and various plants differ only with regard to the method of heating the tunnels. Steam or hot-air pipes are often employed, or parallel flues underneath the tunnel floor may be used. The green bricks, as they come from the moulds, are loaded on cars and run slowly through these tunnels. The temperature to which the tunnels are heated seldom exceeds 120° F.

Burning of Bricks. — Clay wares are burned in a variety of kilns, but these all operate with either an updraft or downdraft. The simplest and earliest type of kiln with rising draft is known as a "scove" kiln and is still in use at many smaller plants. These kilns are temporary in nature and are generally constructed from the bricks which are to be burned.* The bricks are set in large rectangular blocks, 38 to 50 courses high. As the mass is built up a series of parallel arches are left running through the mass from side to side. The entire mass is then surrounded by a wall of brick, which is daubed over with clay to confine the heat within. The fire is built in the arch-like openings underneath the pile.

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* See Ries, "Clays," p. 273.

In downdraft kilns[*] the heat is conducted by suitable flues to the top of the kiln chamber, and then down through the ware, whence it is carried out to the stock through flues in the bottom. The bricks on the top receive the greatest heat, while in the updraft type the brick on the bottom get the most heat. The advantage is with the downdraft kiln, for should the top bricks' become overheated or semifused, no damage would result to the main mass beneath. But in the case where the bottom brick become overheated or fused, they will cause the entire mass to sag and perhaps topple over, thus ruining the entire batch.

The latest type of kiln, however, and the ones in use in the larger plants are known as continuous kilns. These were originally designed to utilize the waste heat in burning. They consist essentially of a series of chambers arranged in a line, or circle, and connected with each other and also with a central stack by means of flues. Each chamber holds about 22,000 bricks. When the chamber is first fired, the water vapor, smoke, etc., is conducted to the stack for a brief period, but as soon as this ceases, the heat and gases are conducted to the next chamber ahead and forward through several chambers, preheating them before they are actually fired. There is thus a wave of maximum temperature continually passing along the line, ahead of which the kilns are being preheated and behind which the kilns are being cooled and emptied of their finished ware.

Clay Output of the United States. — Owing to the fact that most clay products are manufactured by the producer, and no record is kept of the raw material, the figures for the value and production of clay must be for the manufactured product. In 1907, according to the United States Geological Survey, the total value of brick, tile and pottery manufactured in the United States was $158,942,369. The year 1908 was remarkably dull in the building trades, and the production of clay products showed a great falling-off for that year, the total value being $133,197,762. Of this total figure brick and tile furnished about 81 per cent of the value. In 1909 the production showed a substantial increase, valued at $166,321,213; in 1910 it amounted to $170,115,974. Accurate figures for 1911 are not available at this time.

Sand-Lime Brick. — These brick are made by mixing and tempering together quarry san [illegible] nd quartzite with at least

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[*] See [illegible]

6 per cent slaked lime, moulding under severe pressure and bonding in cylinders under the influence of steam at a pressure of about 8 atmospheres for a period of from 6 to 16 hours.

The industry has grown so much in Holland and Germany (and to a less degree in the United States), and the brick are applied to so many purposes (e.g., building, paving, flue and chimney construction) that the clay workers have found their trade threatened. The building departments of the larger cities and the government of Holland and certain states in Germany have permitted and encouraged the development of this new industry.

The following digest of methods employed in Dutch factories may present a general view of European procedure.*

Seven factories slake the lime in trommels, in one with a pressure increasing gradually to 10 atmospheres. Some sift the lime after slaking. One grinds the slaked lime in a ball mill, digests the mill material in a silo for four days and then screens it. Three works use a silo in which the material lies for 8, 14 and 24 hours respectively. The slime is slaked by hand in three other factories, one of which stores the slaked material for two months in covered sheds. Lime and sand are measured out carefully; generally the proper proportions of charge are thrown into cars divided by a moveable partition. Mixing machines of the screw-worm and pan or edge-runner type are used. Moulding and pressing is done by dry-press machines, or by means of presses with turntables. The bricks are hardened in cylinders under a pressure of 8½, 8, 7 and 6 atmospheres during a period of from 8 to 16 hours (depending on the factory). All firms use saturated steam, but one finishes the hardening by passing superheated steam into the cylinder. The latter, however, uses a wetter charge than is usual. The object in all cases is to effect the formation of an aqueous calcium metasilicate, which is formed at the temperature obtaining in the trommel, namely 500 to 800° C., a temperature about 500° C. lower than the temperature of formation of dry calcium bisilicate in furnace operations.

The mortar recommended for sand-lime brick consists of 1 part Portland cement and 3 parts sand; another mixture consisted of 1 part lime, 2 parts sand and 1¼ parts natural cement.

The chemistry of the operation of hardening has been studied by Dr. T. R. Ernest.† The quantity of combined water and of soluble silica varies widely in the same factory. A high percentage of soluble silica, along with a good structure in the fracture of the brick, indicates strength and quality. Both calcium metasilicate and orthosilicate are present as well as the disilicate.

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* *Thonindustrie Zeitung*, Feb. 22, 1912.

† Ibid., Jan. 18, 1912.

$$\begin{aligned} Ca(OH)_2 + SiO_2 &\rightleftarrows CaSiO_3H_2O. \\ CaSiO_3H_2OCa(OH)_2 &\rightleftarrows Ca_2SiO_4 + H_2O. \\ Ca(OH)_2 + 2\,SiO_2 &\rightleftarrows CaH_2Si_2O_6. \end{aligned}$$

These salts bind the solid grains together and knit the brick into a homogeneous mass. The chief of these salts in quantity and efficiency is the metasilicate $CaSiO_3H_2O$.

A Comparison of the Usefulness of Sand-Lime and Ordinary Burned-Clay Brick. — Holland, Germany, the United States and other countries are witnessing constant disputes between manufacturers of sand-lime and clay bricks, and are desirous of some exact report on the real merits of the questions at issue. Since the manufacture of sand-lime brick in America is in a less advanced stage of development than in Europe, the bitterness of the disputes between the clay and sand-lime workers has not reached the intensity of the quarrels of the European operators.

In order to determine the respective merits of the products of the two parties, the Holland Minister for Agriculture, Trade and Commerce appointed a Commission to investigate the qualities of the Holland sand-lime bricks and to compare these bricks with the clay bricks produced in this country. This Commission has handed in its report under the title, "Verslag van de Commissie tot onderzook van Kalkzandsteen," and in the form of a book of 264 pages, containing numerous illustrations and tables. The report is apparently thorough, scientific and practical, and should meet with the attention of all engineers and architects.

The conclusions arrived at may be summed up as follows:

The sand-lime brick has "arrived" and deserves to be seriously considered as a building material, and its properties assure it a place in the building world of no less honor than the clay brick. Where great demands are made of a structure, and wherever this structure is to remain for eternity, the clay bricks should have preference, or rather, certain recognized and tested brands of clay bricks, for the principal reason that we have no test of the effect of time on the sand-lime brick.

Furthermore, it appears that the sand-lime bricks are, as a rule, more vulnerable to the attacks of frost than clay bricks, although in some instances the sand-lime bricks behave better than the clay bricks. Acids and acid waters attack the sand-lime bricks much more rapidly and very soon destroy their surface. This is of importance whenever building operations are carried out in swamp lands or drained marshes. In examining the foundations of old Dutch houses there was a great difference in the durability of the brick walls. Some remained intact, while others were almost completely destroyed by the acid in the water.

In the degree of resistance to mechanical forces the sand-lime brick varies according to the quality of the bond, but on the whole the Commission determined that the clay brick insured greater security to shock and other mechanical influences.

In the use of some special kinds of sand-lime blocks as paving stones, some pavements show exceedingly good results in all the tests applied, yet the Commission feels warranted in raising a note of warning against the general application of the sand-lime brick for paving, particularly in cases where it may be exposed to the attacks of running water.

In structures in contact with water the Commission determined that the sand-lime brick was not a suitable material. At the same time it determined that the ordinary Dutch brick was less suited to such structures than many foreign bricks which showed less vulnerability to the attacks of frost.

In building construction the sand-lime bricks may be used without fear and as widely as clay bricks, as long as architectural considerations do not forbid their application. An examination of the façades of houses which have been exposed to severe cold demonstrated that good sand-lime bricks resisted such attacks as well as clay. For inside walls and for such as do not carry a heavy load second-class sand-lime bricks are quite satisfactory.

The ring of the sand-lime brick is no indication of its quality. The Commission found that the bricks which rang clearest offered the least resistance to their tests. The only reliable test to determine the quality of the sand-lime brick is the mechanical compressive test.

The Commission suggests the following demands of Holland sand-lime brick:

1. The brick must show a homogeneous and firm structure on the cross section.

2. When dry the brick should stand not less than 200 kg. to the square centimeter in bricks of first quality and a pressure of not less than 150 kg. to the square centimeter in bricks of the second quality, this to be the average of ten bricks tested, of which none should show a resistance less than 180 kg. and 135 kg. to the square centimeter, respectively.

3. The water absorption of the dry brick should not be more than 15 per cent of its weight.

With regard to the resistance of a sand-lime brick to the action of fire the Commission drew attention to the fact that this was not a vital question, since granite, which is one of the best building materials, falls to pieces when exposed to excessive heat. In all buildings which use both ordinary brick and fire brick to obtain some degree of fire resistance, the sand-lime brick may also be used in place of the ordinary clay brick. The Commission is of the opinion that the sand-lime brick is not less fireproof than the ordinary clay brick. In Berlin the building police permit the construction of chimneys and flues of sand-lime bricks.

Finally, the Commission is of the opinion that sand-lime bricks should not be used for façades of buildings which have any style or beauty, and particularly warns against their use in cities.

The character of the tests made by the various members of the Commission and the experts employed is described quite fully in *Thonindustrie Zeitung*, February 22, 1912.

APPENDIX

Quantities of Refractory Bricks and Blocks Used in Constructing Furnaces

Approximate Count of Refractory Material used in Building One 60-Ton Basic Open-hearth Furnace

Shown on Fig. 53, page 135.

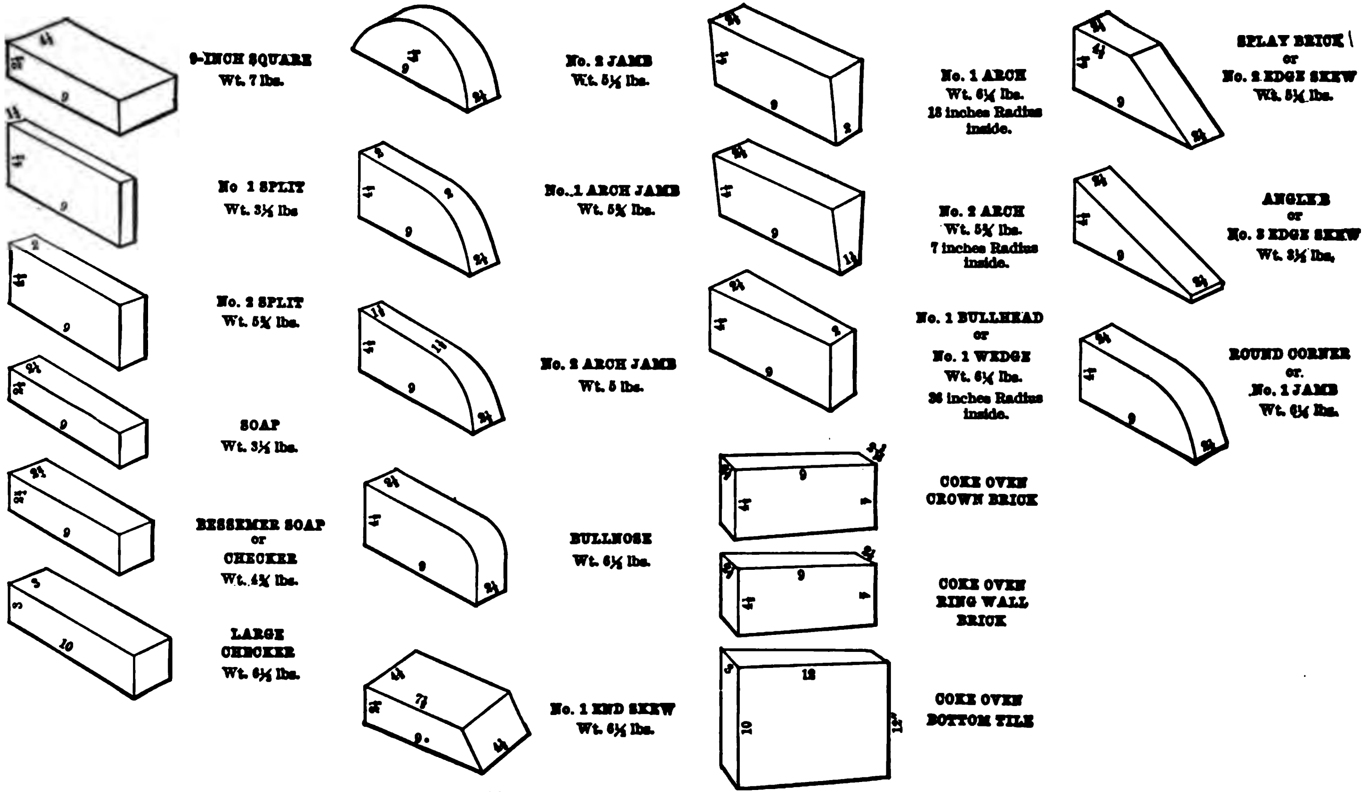
No. of pieces.	Shape and where used.	Quality.	Approx. 9-in. equivalent.
200,000	Foundations and side walls............	Red bricks	200,000
80,000	Checkers in regenerative chambers.....	Fire bricks	80,000
70,000	Side walls of regenerative chambers....	Fire bricks	70,000
50,000	Side walls of flues and pipe lining......	Fire bricks	50,000
270,000	Side walls and roofs over slag pockets and furnace........................	Silica	270,000
30,000	Side walls and bottom of furnace	Magnesia Chrome	30,000
	Total		700,000

It will require 48 tons of magnesite to install bottom of above furnace.

Approximate Count of Refractory Material used for Lining One Rotary Cement Kiln, 150 Feet Long and 8 Feet Diameter Shell

Fig. 77, page 205.

No. of pieces.	Shape and where used.	Approx. 9-in. equivalent.
35	Fire clay, No. 20 hot zone.........................	273
5,000	Fire clay, No. 96 R. K. blocks hot zone.............	15,000
1,632	Fire clay, No. 96 R. K. blocks hot zone.............	4,896
8,534	Fire clay, No. 22 cold zone.........................	17,921
33	Fire clay, No. 21 cold zone.........................	125
15,234	Total	38,215



Shapes and Sizes of Refractory Bricks.

APPROXIMATE COUNT OF REFRACTORY MATERIAL USED FOR ONE BELGIAN OR LONG OVEN, 34 FEET LONG, 5 FEET WIDE AND 8½ FEET HIGH

Fig. 49, page 127.

No. of pieces.	Shape and where used.	Approx. 9-in. equivalent.
2880	No. 1 wedge lime-bond silica crowns	2880
1925	9-inch straights, lime-bond silica crowns	1925
10	Soaps, lime-bond silica crowns	10
25	Wedge soaps, lime-bond silica crowns	25
80	Crown skews, lime-bond silica crowns	320
1	Trunnel head, lime-bond silica crowns	25
1	Fire-clay hopper ring	25
1300	Fire-clay liners — 9-inch straights	1300
25	Fire-clay soaps — liners	25
138	Fire-clay 15×9×4½-inch liners	869
4	Fire-clay front No. 23	25
8	Fire-clay front No. 22	37
8	Fire-clay front No. 21	48
2	Fire-clay front No. 500	26
2	Fire-clay front No. 501-R	26
2	Fire-clay front No. 501-L	26
2	Fire-clay front No. 502-R	27
2	Fire-clay front No. 502-L	27
2	Fire-clay front No. 503-R	28
2	Fire-clay front No. 503-L	28
2	Fire-clay front No. 504-R	29
2	Fire-clay front No. 504-L	29
2	Fire-clay front No. 505-R	30
2	Fire-clay front No. 505-L	30
2	Fire-clay front No. 506-R	42
2	Fire-clay front No. 506-L	42
165	Fire-clay bottom tile 12×12×12×3 inches	743
1200	Fire-clay fillers — 9-inch straights	1200
7796	Total	9847

APPROXIMATE COUNT OF REFRACTORY MATERIAL USED IN LINING A BLAST FURNACE OF THE FOLLOWING DIMENSIONS

Bottom:—24 feet 6 inches in diameter (outside) and 6 feet deep.

Furnace:—85 feet in height, and 15 feet in clear diameter at stockline, 21 feet 6 inches at upper bosh, and 14 feet 6 inches at hearth.

Fig. 43, page 113.

No. of pieces.	Shape and where used.	Approx. 9-in. equivalent.
2,928	Bottom blocks, 18×12×8 inches fire clay	53,290
4,930	Hearth lining, 9×6 inches keys fire clay	6,574
2,039	Hearth lining, 9×6 inches straights fire clay	2,718
12,510	Hearth lining, 13½ inch- No. 2 keys fire clay	25,020
4,412	Hearth lining, 13½ inch- straights fire clay	8,824
10,795	Bosh lining, 9×6 inches keys fire clay	14,394
6,455	Bosh lining, 9×6 inches straights fire clay	8,607
6,480	Bosh lining, 13½ inch- No. 2 keys fire clay	12,960
3,852	Bosh lining, 13½ inch- straights fire clay	7,704
11,900	Lower inwall, 9×6 inches keys fire clay	15,867
11,095	Lower inwall, 9×6 inches straights	14,793
18,630	Lower inwall, 13½ inch- No. 2 keys fire clay	37,260
15,902	Inwall lining, 13½ inch- straights fire clay	31,804
16,575	Middle inwall, 9×6 inches keys fire clay	22,100
11,480	Middle inwall, 9×6 inches straights fire clay	15,307
31,050	Middle inwall, 13½ inch- No. 2 keys fire clay	62,100
20,724	Middle inwall, 13½ inch- straights fire clay	41,448
9,435	Upper inwall, 9×6 inches keys fire clay	12,580
6,150	Upper inwall, 9×6 inches straights fire clay	8,200
18,720	Upper inwall, 13½ inch- No. 2 keys fire clay	37,440
9.451	Upper inwall, 13½ inch- straights fire clay	18,902
3,024	Upper inwall, No. 27—31½×4×12$\frac{1}{32}$×9 inches fire clay	42,336
80	Upper inwall, No. 28—31½×4×8 inches fire clay	848
728	Gas up-take arch, No. 4 arch, 9 inch- fire clay	2,184
1,092	Gas up-take arch, No. 5 arch, 9 inch- fire clay	3,276
104	Gas up-take arch, No. 4 arch, 13½ inch- fire clay	468
156	Gas up-take arch, No. 5 arch, 13½ inch- fire clay	702
240,797	Total	507,706

* APPROXIMATE COUNT OF REFRACTORY MATERIAL USED FOR ONE BEEHIVE COKE OVEN OF 12.6 INCHES IN DIAMETER AND 7 FEET 7½ INCHES HIGH

Fig. 48, page 126.

No. of pieces.	Shape and where used.	Approx. 9-in. equivalent.
1	60–R fire clay — door jamb	18
1	60–L fire clay — door jamb	18
1	61–R fire clay — door jamb	18
1	61–L fire clay — door jamb	18
1	62–R fire clay — door jamb	16
1	62–L fire clay — door jamb	16
1	63–R fire clay — door jamb	16
1	63–L fire clay — door jamb	16
1	64–R fire clay — door skew	22
1	64–L fire clay — door skew	22
7	65 fire clay — door arch	189
1	42 fire clay — trunnel head	25
1	67–1 fire clay trunnel head	27
148	14 fire clay — floor tile	666
1416	No. 1 keys fire clay — side wall liners	1416
3368	No. 1 wedge fire clay — crown	3368
4951	Total	5875

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* Submitted by courtesy of The Harbison-Walker Refractories Company.

Weights of Various Materials

Material.	Average per cu. ft., pounds.
Brick	
Common red	100
Fire clay	150
Silica	128
Chrome	175
Magnesia as brick or fused in furnace	160
Cement	
Portland	78
Hydraulic	60
Fine Ground Clays, Silica Cement, Etc.	
Fire clay	85
Silica cement	75
Magnesia cement	127
Chrome cement	135
Grain magnesite (as shipped)	112
Coal and Coke	
Anthracite	60
Bituminous	49
Charcoal	18.5
Coke	26.3
Concrete	
Cement, fine	137
Rubble, coarse	119
Earth	
Loam, dry, loose	76
Loam, packed	95
Loam, soft, loose mud	108
Loam, dense mud	125
Sand	
Dry and loose	100
Dry and packed	110
Wet and packed	130
Gravel packed	118
Grain	
Corn	45
Oats	24
Wheat	48
Lime	
Quick, loose lumps	53
Quick, fine	75
Stone, large rocks	168
Stone, irregular lumps	96
Masonry	
Granite or limestone	165
Mortar, rubble	154
Dry	138
Sandstone, dressed	144
Metals	
Aluminum	166
Brass, cast	524
Bronze	534
Copper, cast	537
Copper, rolled or wire	555

Weights of Various Materials (*Concluded*).

Material.	Average per cu. ft., pounds.
Metals (*Continued*)	
Iron, cast	450
Iron, wrought	482
Lead, cast	708
Steel, cast	490
Steel, rolled	495
Tin, cast	459
Zinc, cast	438
Petroleum	55
Wood	
White oak	50
Rock	
Chalk	145
Granite	165
Gypsum	143
Sandstone	144
Pumice	57
Quartz	165
Salt, coarse	45
Shales	162
Slate, American	165
Water at 32° Fahrenheit	62.4

FURNACE-TEMPERATURE DETERMINATIONS *

	Degrees C.	Degrees F.
1. *Gold Melting* (*Royal Mint*).		
Standard alloy, pouring into moulds	1180	2156
Standard alloy, pouring into moulds, by thermocouple	1147	2097
Annealing blanks for coinage, temperature of annealing chamber	890	1634
2. *Silver Melting* (*Royal Mint*).		
Standard alloy, pouring into mould	980	1796
3. *Steel Melting* (*10-ton Open-hearth Furnace, Woolwich Arsenal*).		
Steel, 0.3 per cent carbon, pouring into ladle	1645	2993
Steel, 0.3 per cent carbon, pouring into large mould	1580	2876
Reheating furnace, temperature of interior	930	1706
Cupola furnace, temperature No. 2, cast iron pouring into ladle	1600	2912

DETERMINATIONS BY PROF. LE CHATELIER

	Degrees C.	Degrees F.
4. *Six-ton Converter.*		
Bath of slag	1580	2876
Metal in ladle	1640	2984
Metal in ingot mould	1580	2876
Ingot in reheating furnace	1200	2192
Ingot under hammer	1080	1976
5. *Open-hearth Furnace* (*Siemens, Semi-Mild Steel*).		
Fuel gas near generator	720	1328
Fuel gas entering into bottom of regenerator chamber	400	752
Fuel gas issuing from regenerator chamber	1200	2192
Air issuing from regenerator chamber	1000	1832
6. *Chimney Gases.*		
Furnace in perfect condition	300	590
7. *Open-hearth Furnace.*		
End of the melting of pig charge	1420	2588
Completion of conversion	1500	2732
8. *Molten Steel.*		
In the ladle — commencement of casting	1580	2876
In the ladle — end of casting	1490	2714
In the moulds	1520	2768
For very mild (soft) steel the temperatures are higher by 50° C.		
9. *Siemens' Crucible or Pot Furnace*	1600	2912
10. *Rotary Puddling Furnace*	1340–1230	2444–2246
Puddled ball — end of operation	1330	2426
11. *Blast Furnace* (*Gray-Bessemer Pig*).		
Opening in face of tuyere	1930	3506
Molten metal — commencement of fusion	1400	2552
Molten metal — end, or prior to tapping	1570	2858

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* Made by Prof. Roberts Austen and others.

	Degrees C.	Degrees F.
12. *Red-brick Kiln (Hoffmann's).*		
Burning temperature	1100	2012
13. *Foundry Irons and Steels.*		
Melting heat of white cast iron	1135	2075
Melting heat of gray cast iron	1220	2228
Melting heat of mild steel	1475	2687
Melting heat of semi-mild steel	1455	2651
Melting heat of hard steel	1410	2570
14. *Porcelain Furnace (for Hard Porcelain).*		
Heat at the end of baking	1370	2498
15. *Incandescent Lamps.*		
Heat burning normally	1800	3272
Heat when pushed	2100	3812
16. *Blast Furnace for Copper Ores at Tuyeres*	1200–1500	2192–2732
17. *Blast Furnace for Lead Ores at Tuyeres*	1100–1300	2012–2372
18. *Reverberatory Furnace for Smelting Copper Ores*	1300–1500	2372–2732

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